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Soil Stabilization Mat For Lunar Launch/ Landing Site

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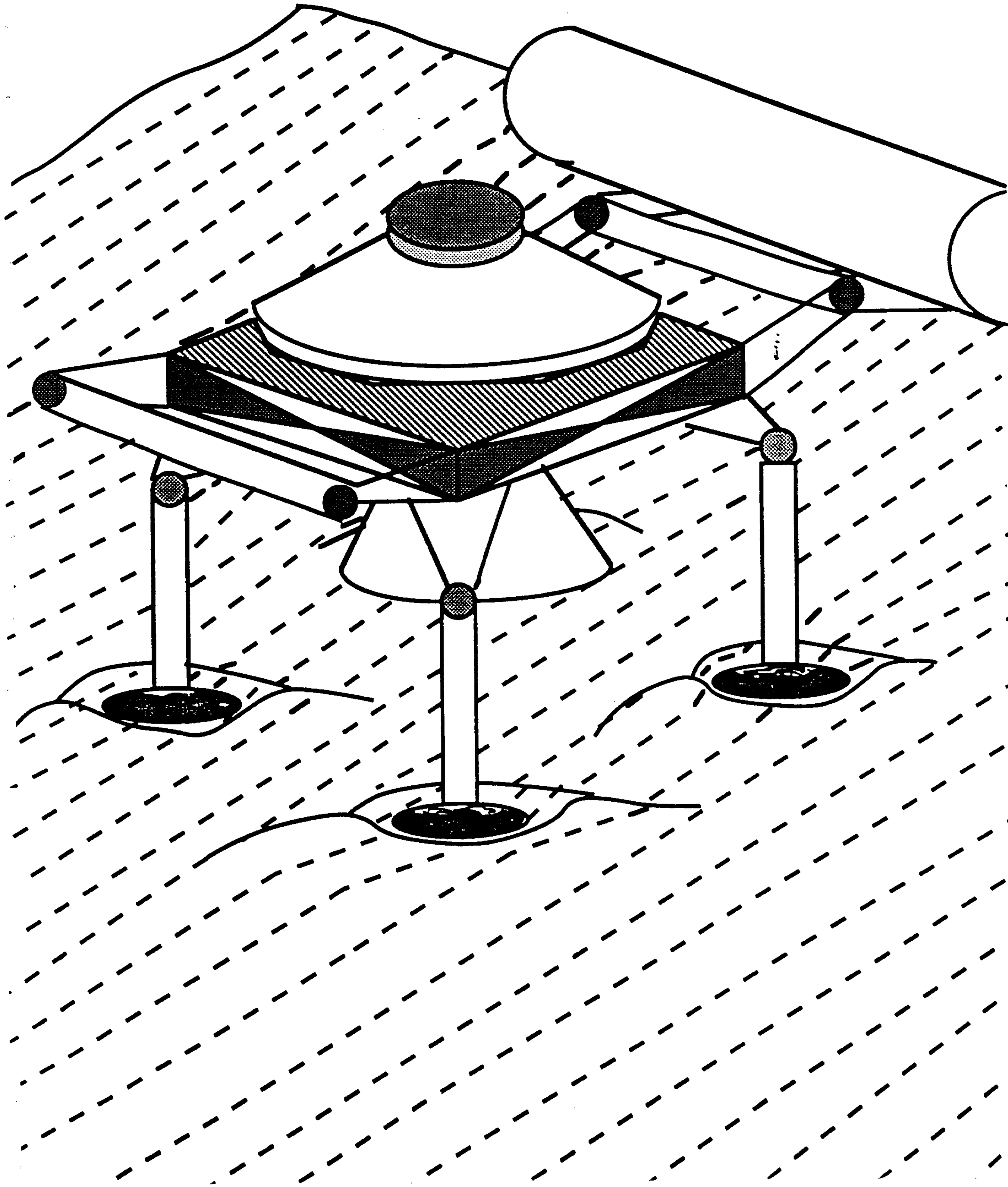

ABSTRACT

The dawn of a lunar colony is gradually approaching. This lunar colony, just like the colonies of ancient Empires will require adequate supply lines for essentials such as equipment and supplies. In the case of the proposed lunar colony, these supply lines will extend between the Earth and the Moon. Accordingly, there will be a significant increase in the traffic between the two. As a result, facilities which are capable of handling the frequent arrivals and departures of these spaceships are necessary.

The facility must be able to provide these services with minimal interruption of operational activity within the colony. The major concerns associated with the space traffic are the dust and rock particles that will be kicked up by the rocket exhaust. As a result of the reduced gravitation of the Moon, these particles scatter over large horizontal distances. This flying debris will not only seriously interrupt the routine operations of the colony, but could cause damage to the equipment and facilities surrounding the launch site.

The following paper presents an approach to overcome this problem. A proposed design for a lunar take-off/landing "mat" is presented. This proposal goes beyond dealing with the usual problems of heat and load resistances associated with take-off and landing, by solving the problem of soil stabilization at the site. Through adequate stabilization, the problem of flying debris is eliminated.

PROBLEM STATEMENT

With the advent of a lunar colony, a need arises for facilities to handle frequent arrivals and departures of transport vehicles from Earth. Specifically, a launch/landing pad capable of accommodating these vehicles is necessary. These subsequent take-offs and landings should not interfere with any ordinary, everyday routine operations of the colony. One problem of significant concern is the dust and rock particles which will be kicked up by the rocket engines. Due to the reduced gravity on the moon, these particles travel significant horizontal distances from the actual landing site. This flying debris could interrupt the routine of the colony and even result in significant damage to equipment or injury to personnel, therefore, this problem must be eliminated.

The objective of this project is to provide adequate soil stabilization for the proposed launch/landing site. The design must provide a structure or surface capable of accommodating a spacecraft and protection from flying particles. In addition, the design must be of adequate size to guard against landing errors. Lastly, the pad should be capable of withstanding one landing/launch sequence every three months over a lifetime of ten years. The constraints in the design include:

1. adequate heat resistance for take-off
2. sufficient impact resistance on landing
3. resistance to radiation (UV and Gamma)
4. ease of transportation and deployment
5. low weight

The mat is 66 mils or 0.066 inches thick and weighs approximately 30,500 pounds. The carbon fiber mat is produced by joining together forty fabric panels that are 100 meters long and 2.5 meters wide. Forty fabrics panels are necessary to cover a one-hundred meter square area. These panels are stitched together using double stitched and flat-felled seams. The strongest seams are double-stitched and flat-felled. A carbon yarn will be used for the stitching. Hand sewing may be necessary when stitching.

A flat-felled seam, figure 2, is one in which the fabric edges are wrapped around each other into interlocking "J's" and sewn together with double seams. By using these seams, there are no open raw edges for the high velocity gases to pry apart the strips of fabric. Double-stitched means that there are two threads instead of the one. The layers are connected by stitching along the edges of each layer and along the seams of the panels. Securement of the mat to the moon's surface is unnecessary because the high mass of the mat will prevent significant movement.

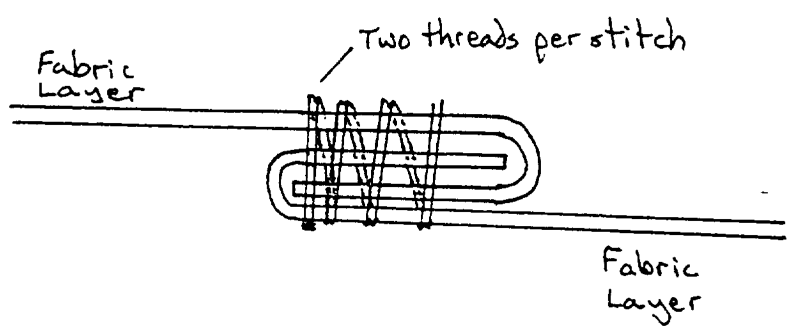

Figure 2. Flat-felled Seam

DESCRIPTION

The mat to be used at the landing and take-off site is a double layer fabric made of carbon fibers which are inherently black. The Fiberite Corporation produces a woven carbon fabric in a 2 x 2 basket weave. A 2 x 2 basket weave, figure 1, is the best woven fabric design for this particular application. The reason is due to the higher tear strength, crease resistance, and abrasion resistance. This weave is especially good at preventing further propagation of tears. The increase in tear resistance is due to the yarns being able to move and accommodate a weight during loading. The longer float length is responsible for the better properties in abrasion resistance. A longer float creates a larger area of contact between the yarns and the abradiant. The increased area reduces the degree of friction. The crease resistance is lowered due to the ability of the yarns to move with respect to each other under a load. The mat will experience loads during transportation that may lead to creases.

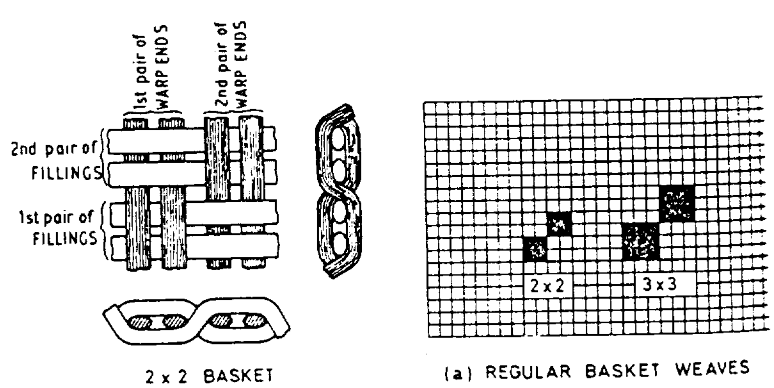

Figure 1. Basket Weave

ANALYSIS

A. Soil Characteristics

The composition of the lunar surface is categorized in the following manner. The very top surface layer consists of extremely fine particles. These particles are similar in nature to those that are found here on Earth on certain "volcanic beaches". This layer is approximately 5 cm deep. Below this layer, there exists a very dense, compressed layer of regolith. The purpose of this design is to prevent the soft surface layer from being scattered by the rocket. The mat's design prevents particles of greater than 1 micrometer from passing through the mat.

B. Material

The strategy of material selection for a launch and landing mat involves finding a fabric that adheres to the following criteria: low porosity, low density, as well as resistance to heat, tears, and radiation (UV, Gamma). These parameters are extremely important for lunar applications. Other criteria are important, but the above stated parameters are the most important in order to prevent major mechanical failures of the mat. Investigation of various materials leads to a list of possible classes of fibers. These classes are metal, organic, and ceramic fibers. Carbon fibers possess the characteristics needed for this lunar application. There are various methods of producing carbon fibers. These processes involve precursors such as polyacrylonitrile (PAN), cellulosic (rayon), and pitch. PAN and rayon precursors result in moderate to high modulus fibers. The pitch based fibers are capable of having low or high modulus carbon fibers, but are not strong enough for this design application. The fabrication of carbon (PAN) fibers is covered in Appendix A. This lunar application demands a fiber with a moderate modulus to prevent permanent creasing of the mat during the transportation to the moon. A PAN based carbon fiber woven fabric is produced by the Fiberite Corporation.

Porosity is important for the launch and landing mat due to the high velocity gases that the mat will be exposed to. Using two layers will greatly reduce the amount of gases that will penetrate to the moon's surface. The weave of the fabric must prevent as much of the gases as possible from penetrating the fabric, thus reducing the chances of the mat to fail mechanically. If the soil escapes through the mat, erosion of the space craft as well as any structures in the surrounding area is possible. The second layer of the mat will greatly reduce the chances of debris from fully escaping through the mat as well as adds extra strength.

Density is important because the cost of transporting the mat in the space shuttle is extremely high (25,000 dollars/pound) compared to any production costs. Common metallic wire densities range from 7 to 20 g/cc. The densities of organic materials are lower, they range from 1 to 4 g/cc. The densities of ceramic fibers range from 1.5 to 8 g/cc. Carbon fiber densities range from 1.6 to 2.3 g/cc. Organic and ceramic fibers appear to be the best choice when considering only densities. Organic fibers are unacceptable due to other factors that will be addressed in the following sections. The density of the carbon fiber being used in the mat is

1.91 g/cc. The maximum cargo load of the space shuttle is 60,000 pounds. The weight per unit area of one layer of fabric is 20.00 oz/sq.yd, therefore, the double layer weight is 30,500 pounds. This value includes the extra weight of threads for the seams and is based on an area of 100m x 100m. The seam weight is based upon two percent of the weight of a single layer.

Heat resistance is important because of the temperatures encountered during landings and take-offs from the moon. The maximum temperatures from the exhaust gases are approximately 1500 degrees Celsius, however, the maximum exposure time is only a few seconds. Ceramic and metallic fibers are capable of withstanding this temperature range and exposure time. The melting temperatures of metallic fibers range from 1300 to 2600 degrees Celsius. The organic fibers are only capable of enduring temperatures of approximately 200 to 300 degrees Celsius. The melting temperatures of ceramic fibers are approximately from 800 to 3600 degrees Celsius. The maximum temperature usage for carbon fibers is approximately 2000 degrees Celsius.

Tear resistance is important due to the forces that will be endured during landings as well as the deployment of the mat. The lunar surface is not level, therefore, consideration of the possibilities of tears need to be addressed. Lunar rocks are present on the moon and are not capable of being cleared from the proposed landing area. The mat must be capable of withstanding the forces applied to the mat over the rocks. The use of a basket weave increases the tear resistance in the warp and weft direction. This effect is due to the yarns in the mat being able to move with respect to one another which presents bundles of yarn to the load, therefore, increasing the tear resistance. The tear will not propagate using the basket weave.

All types of radiation are important because the mat should not deteriorate upon exposure. This deterioration often results in a major loss in mechanical properties. The organic fibers degrade and lose mechanical properties when exposed to ultra-violet and gamma radiation. Metallic and ceramic fibers are capable of retaining mechanical properties with exposure to these types of radiation.

The criteria addressed in the above paragraphs enables a decision to be made on the selection of a material. The advantages and disadvantages of each class were given in the preceding paragraphs. A decision matrix was used to aid in the material selection and can be found in Appendix B. Evaluation of the criteria and the decision matrix lead to the decision to use carbon fibers. The carbon fibers are the only class that effectively adhere to all of the criteria.

C. Stowage

The mat is to be stowed on board the space shuttle for transport to the moon. It is therefore mandatory that the 100m x 100m mat be able to fit into the 12m x 6m x 6m volume of the space shuttle bay. The folding method involves folding the mat in an accordion fashion in one direction and then subsequently rolling it in the other direction. This method is shown in figure 3 of the following page. Considerations in determining the folding scheme primarily involve reducing the volume of the mat to proportions

FOLDING METHOD

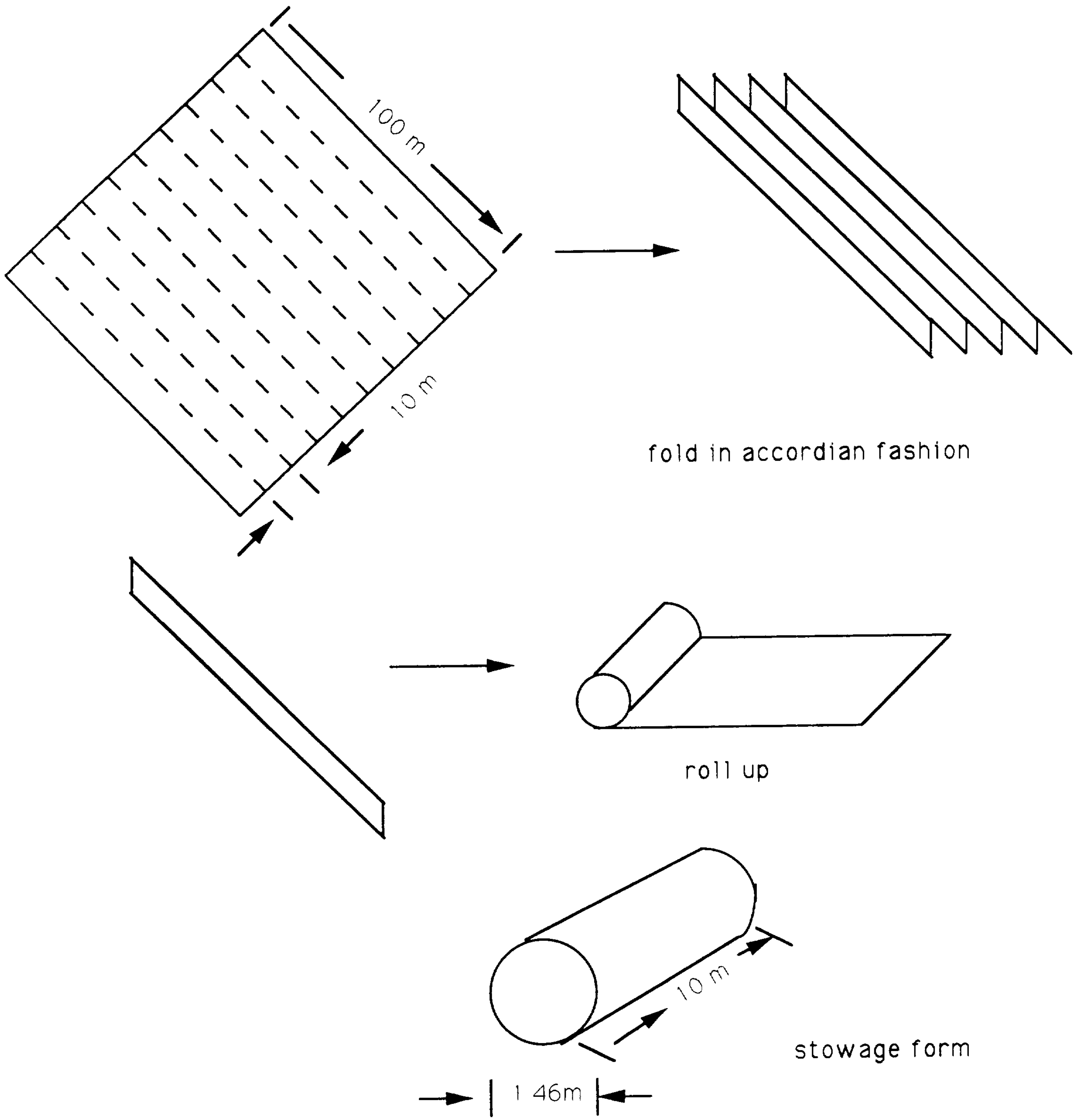

Figure 3.

acceptable for the shuttle. The design chosen minimizes this volume. The other consideration is the possibility of over stressing the mat at the folds if it is over folded. This situation may result in significant tearing or other mechanical failures. The use of of 2 x 2 basket weave helps to eliminate the amount of stress at the folds on the mat. This design also minimizes the number of folds to an acceptable level.

D. Deployment

The method for deploying the mat is shown in figure 4 of the following page. First the mat is to be unrolled by metal strips which were rolled up inside the mat. These strips serve as coil springs and give the necessary rotational force. Unfolding the mat is accomplished by a harpoon like device. The harpoon is to be attached to the edge and then fired in the direction of unfolding, with sufficient thrust, the harpoon carries the mat to a nearly deployed state. Minor adjustments as needed can be done either by humans or a small robot

E. Vehicle Parameters

The lunar mat is designed for the landing and launching of space vehicles. The size of these vehicles vary from approximately 11 to 62 feet in length and 10 to 20 feet in diameter. The ranges of weight of these vehicles are 20,000 to 35,000 pounds plus a cargo weight up to 60,000 pounds. Therefore, the total load reaches a maximum weight of 95,000 pounds on Earth.

DEPLOYMENT METHOD

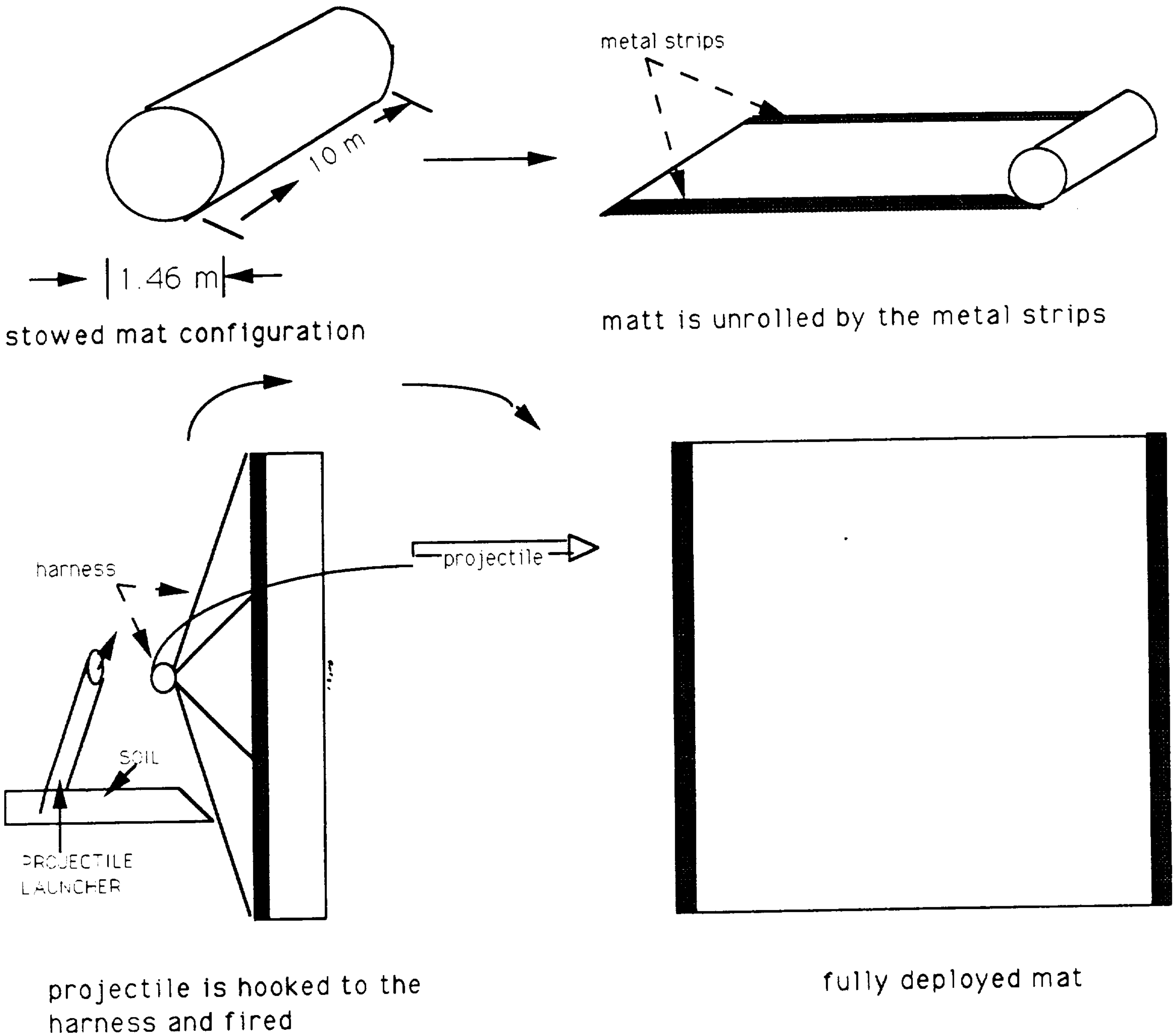

Figure 4.

The exhaust components consist mainly of hydrogen and oxygen. The specific thrust is proportional to the velocity. The ratio is given by 100 (ft/sec) : 3.1056 ((lbf-sec)/lbm). The thrust force can be computed by multiplying the specific thrust by the fuel rate. The average fuel rate is approximately 50.1 (lbm/sec).

F. Performance

1. Take-off

The primary concerns on take-off are the heat of the exhaust gases and the thrust forces associated with the exhaust velocity. With respect to heat parameters, an investigation of the technology of rocket plumes is necessary (such an analysis may be found in Appendix H). All results presented here are based on plume calculations involving a rocket of approximately 95,000 pounds powered by a single engine. Assuming that the fuel to be utilized is liquid oxygen, the maximum temperature of the exhaust gases to be anticipated is approximately 1500 degrees Celsius. Since the mat is constructed uniformly of carbon fibers, which have a temperature resistance of approximately 2000 degrees Celsius, there will be no significant problems with material breakdown. Furthermore, because of the 500 degree safety margin, the pad should be able to hold up in the event of minor modifications in rocket fuel composition which would cause an increase in exhaust temperature.

The anticipated thrust force is approximated by the specific thrust ratio presented earlier. For this determination, the diameter of the rocket varies from approximately 3 to 6 meters in diameter at the exit. These nozzle sizes yield a maximum velocity of approximately 100 m/s^2. Applying the maximum anticipated specific thrust factor, a thrust force of approximately 100 kilo-newtons is calculated. Subsequent stress analysis of the mat (see Appendix G) indicate that the material has a sufficient margin of safety against failure.

2. Landing

The landing sequence will subject the mat to two different conditions. First, the mat will be subjected to rocket blasts that are used to decelerate the vehicle. Secondly, the mat will experience the impact of the craft as it lands. Regarding the rocket blasts the following reasoning was imposed. The duration of these blasts is significantly less than the amount of time that the mat will experience the take-off blasts, therefore heat conduction and porosity effects will not present any concern. Since the rocket utilizes the same fuel as employed in launching, the temperature will not exceed the take-off temperature; therefore, these effects are negligible. The impact force is approximated as being equal to the force obtained were the mass of the space ship dropped from a height of 2 meters. This would equate to a force of about 300 kilo-newtons; this is clearly less than the associated thrust force which would be experienced. As a result, the mat will perform equally well on landing.

G. Weight/Mass/Inertia

The weight of a single layer mat is 20.00 oz/sq.yd. This weight is based on a 2 x 2 basket weave. The mat is going to be two layers with a thickness of 66 mils. The total weight will be approximately 30,500 pounds. The mat will not be moving, therefore, the inertia is zero.

H. Casualty Information

1. Alternate Deployment Method

An alternative deployment method is necessary if the mat can not be properly deployed. The causes for this situation may be due to failure of the rockets or robots. If this situation occurs, the necessary action is to obtain additional rockets or robots.

2. Repair of Damage

The probability of a tear propagating through the mat is necessary to consider. The surface of the moon is not level and rocks may be present underneath the mat. During a landing a tear may initiate if the landing is near the site of the rock. Having two layers of fabric will greatly minimize the probability of tearing both layers. The mat will continue to work satisfactorily with only one working layer. The 2 x 2 basket weave is especially good with the prevention of tear propagation because of weave structure.

I. Maintenance

The carbon fiber mat will not require any maintenance.

J. Cost Analysis

The approximate cost of the mat includes the manufacturing, and transportation cost. The approximate cost of carbon fibers are in the range of 1000 dollars per pound. This cost only represents the production of the fiber. Weaving costs are going to approximately 100 million dollars. The space shuttle transportation cost will be approximately 25,000 dollars per pound. With an approximate mat weight of 31,000 pounds the total cost will be 775 million dollars. The approximate cost of the deployment will be 2 million dollars. This value includes the cost of robots, rockets, and a harness. This cost is small in comparison to the transportation cost.

CONCLUSIONS

The objective of this project was to design a soil stabilization mat to be employed by a lunar colony for the Take-off and landing of various transport vehicles. During the course of this design, all the conditions to be encountered during launch and landing were investigated. On landing, the effects of the accompanying impact were examined. A force analysis was performed to observe how the mat would react. The results of this analysis revealed that the material was indeed of sufficient strength to prevent punctures or tears caused by sharp particles underneath the mat. This was primarily due to the fact that the mat was not in a prestressed state (which would be present as a result of being stretched or anchored).

For the launch sequence a more detailed analysis was performed. The two primary considerations were the thrust force and temperature/heat transfer values to be anticipated. An approximation for the thrust force was obtained using the specific thrust ratio. The temperature effects were estimated after a judicious analysis of typical, single-engine rocket plumes. In both these areas, the mat performed well. There was a 500 degree excess in temperature resistance and an acceptable difference between anticipated loading and estimated failure loads.

Lastly, the porosity of the material was sufficiently low enough to prevent nearly all of the gases from penetrating through. This, in addition to the fact that the blast should terminate approximately 25 m from the edges, should ensure adequate stabilization of the soil. The facts above, together with the efficient stowage and deployment methods proposed should prove the mat to be a very successful design.

RECOMMENDATIONS

Following the detailed analysis presented above, the following recommendations are hereby made. Since the material selected for the mat performed very well in all the critical areas, we suggest that it be employed. Regarding the stowage method, the proposed method is not only simple, but easily fits into the Shuttle cargo bay with plenty of room for other items. It is therefore recommended also.

The deployment method, however, is not as overwhelmingly convincing. The proposed method will work, however, (as noted) in the event of failure, the mat would be difficult to deploy via alternate means. As the sophistication of robots increases, we recommend that further analysis be conducted to possibly find a method which might prove more versatile. We also recommend that there be astronauts present during the deployment who might be able to make corrective adjustments in the event the mat does not deploy as planned, or the robots prove inadequate.

Appendix A

The Fabrication of Carbon (PAN) Fibers

The following paragraphs describe some of the processes necessary to convert the polyacrylonitrile (PAN) fibers into workable carbon fibers. A possible problem with the mat being made of carbon fibers is the possibility of mechanical failure at the folds when the mat is folded into the cargo space. The carbon fibers are inherently brittle and thus tend to break with excessive bending. Without the proper equipment it is beyond the scope of this paper to guarantee that the mat could withstand the stresses at the folds provided the carbon fibers are prepared properly for manufacturing.

There are three precursors used for the production of carbon fibers, including polyacrylonitrile, rayon and other cellulosic fibers, and pitch based fibers. Polyacrylonitrile (PAN) fibers are favored over cellulosic and pitch based fibers due to ease of processing and greater end-use strengths. PAN fibers are heated in oxygen to produce carbon fibers. Carbon fibers produced from PAN fibers have a higher modulus of elasticity than the others, which means that there will be a smaller elongation at break. Special care is required during process operations because the individual filaments in the yarn tend to break easy. The partial breakage of filaments results in yarns which contain large amounts of stray filaments oriented at various angles to the axial direction of the yarn. During further manufacturing processes, small fragments of the stray material are broken off to form an "aerosol" of very short carbon fibers, which is highly undesirable. Bromination is a process that will reduce this problem. High modulus carbon fibers cannot easily be pushed into tightly packed configurations such as a woven cloth, unless the fibers undergo a bromination process. Bromination results in a lowering of the modulus of elasticity which increases malleability. Once the fabric is formed the plasticizer (bromine) is removed. Weaving carbon fibers is extremely difficult unless a size is used. A size is a protective coating which is added to yarns prior to weaving. This coating is necessary because the process of weaving is very abrasive, and since the carbon fibers are brittle they are susceptible to mechanical failure. A dilute solution of a mixture of liquid and solid epoxy resins is found to be ideal. The size will be removed after the formation of the fabric.

It is found that a maximum strain at break of 1% is achieved after a heat-treatment at 1500 degrees Celsius. A strain of 0.5% is achieved with heat-treatment at 2600 degrees Celsius. This indicates that for this design a heat-treatment at 1500 degrees Celsius would be appropriate. Fiber modulus increases with a higher heat-treatment temperature (HTT), but strength generally decreases at 1500 degrees Celsius and continues to decrease at higher temperatures. At a HTT at 1500 degrees Celsius, the fiber strength and strain rate are at a maximum, and thus would be the best temperature to heat treat the PAN fibers.

A very important characteristic of carbon fibers is a low coefficient of thermal expansion. Due to the extreme temperatures, a low coefficient of thermal expansion will result in minimal deformations due to temperature changes.

Prestressed fiber compactions represent a means of achieving high bearing stress levels with relatively low wear rates. It appears that crushing the fiber ends produces a thin layer of fiber debris and thus results in a smooth wear surface. This described mechanism coupled with the already low coefficient of friction suggests that the mat will experience very reduced shear stresses.

E. M. Lenoe performed tests on carbon fabrics which show that carbon fabrics can withstand extreme normal stresses. A 1/2 inch diameter steel indenter was forced into typical specimens. The fibers showed to be capable of supporting high bearing stresses with fairly small deflections.

Appendix B

Decision Matrix for Material Selection

MATERIAL DECISION MATRIX	UV & Gamma Radiation	Heat Resistance	Strength	Work-ability	Density	Cost	Weave-ability	TOTAL
scale:	(5/5)	(5/5)	(4/4)	(4/4)	(3/3)	(2/2)	(5/5)	(28/28)
Spectra	0	0	4	4	3	2	5	18
Kevlar	0	0	3	2	3	2	5	15
Glass	5	0	4	3	2	1	3	18
Alumina (99% Aluminum)	5	5	2	2	2	1	3	20
Steel (0.9% Carbon)	5	2	4	1	1	1	2	16
Tungsten	5	5	4	0	0	1	2	17
Silicone Carbide	5	2	3	3	2	1	3	19
Heat-treated Carbon	5	5	4	2	3	1	3	23
Teflon	0	0	1	4	2	1	4	12
PBI	0	1	1	3	3	1	4	13
Titanium	5	5	4	1	2	1	3	21
Aluminum Silicate	5	5	2	2	2	2	2	20
Boron	5	5	3	3	2	1	3	22

Appendix C

Decision Matrix for Weave Structure

WEAVE STRUCTURE DECISION MATRIX	Crease Resistance	Abraision Resistance	Tear Strength	Porosity	TOTAL
scale:	(5/5)	(3/3)	(5/5)	(3/3)	(16/16)
Plain	3	1	2	3	9
Basket	5	2	5	2	14
Rib	4	2	4	2	12
Twill	4	2	4	1	11
Satin	5	2	4	1	12
Sateen	5	2	4	1	12
Ripstock	4	2	5	2	13

Appendix D

Material Data Sheet

MATERIAL PROPERTIES

	Density (g/cc)	Melting Temp. (C)	Elongation (%)	Tensile Strength (MPa)	Specific Strength (1E8 cm)	UV Resistance	Specific Modulus (1E8 cm)	Tensile Modulus (GPa)
Kevlar	1.4	200	3.8	2400-2800	17-19	poor	4.2-14	60-200
Spectra	1	100	3	3000	32	poor	1.8	175
Glass (99% silicone oxide)	2.5	870	4.8 5.4	3400-4500	18-19	good	2.8-3.4	70 85
Alumina	2.7-3.9	2045	N/A	1400-1700	3.6-6.3	good	4.4-9.7	120-390
Steel (0.9% Carbon)	7.8	1300	N/A	4250	N/A	good	N/A	N/A
Tungsten	19.3	3400	N/A	3850	360	good	N/A	N/A
Silicone Carbide	2.6	1100-1300	N/A	2800	10	good	7.3	190
Heat-treated Carbon	2	2000	1	3000	360	good	N/A	360
Tetrafluoroethylene (Teflon)	2.13-2.22	327	200-400	17-28	N/A	fair	N/A	N/A
Polybenzimidazole (PBI)	1.43	1000	28.5	N/A	N/A	fair	N/A	N/A
Titanium	4.54	1660	N/A	N/A	N/A	good	N/A	N/A
Aluminum Silicate	2.55	1650	N/A	N/A	N/A	good	N/A	N/A
Boron	2.52	2430	N/A	N/A	N/A	good	N/A	N/A

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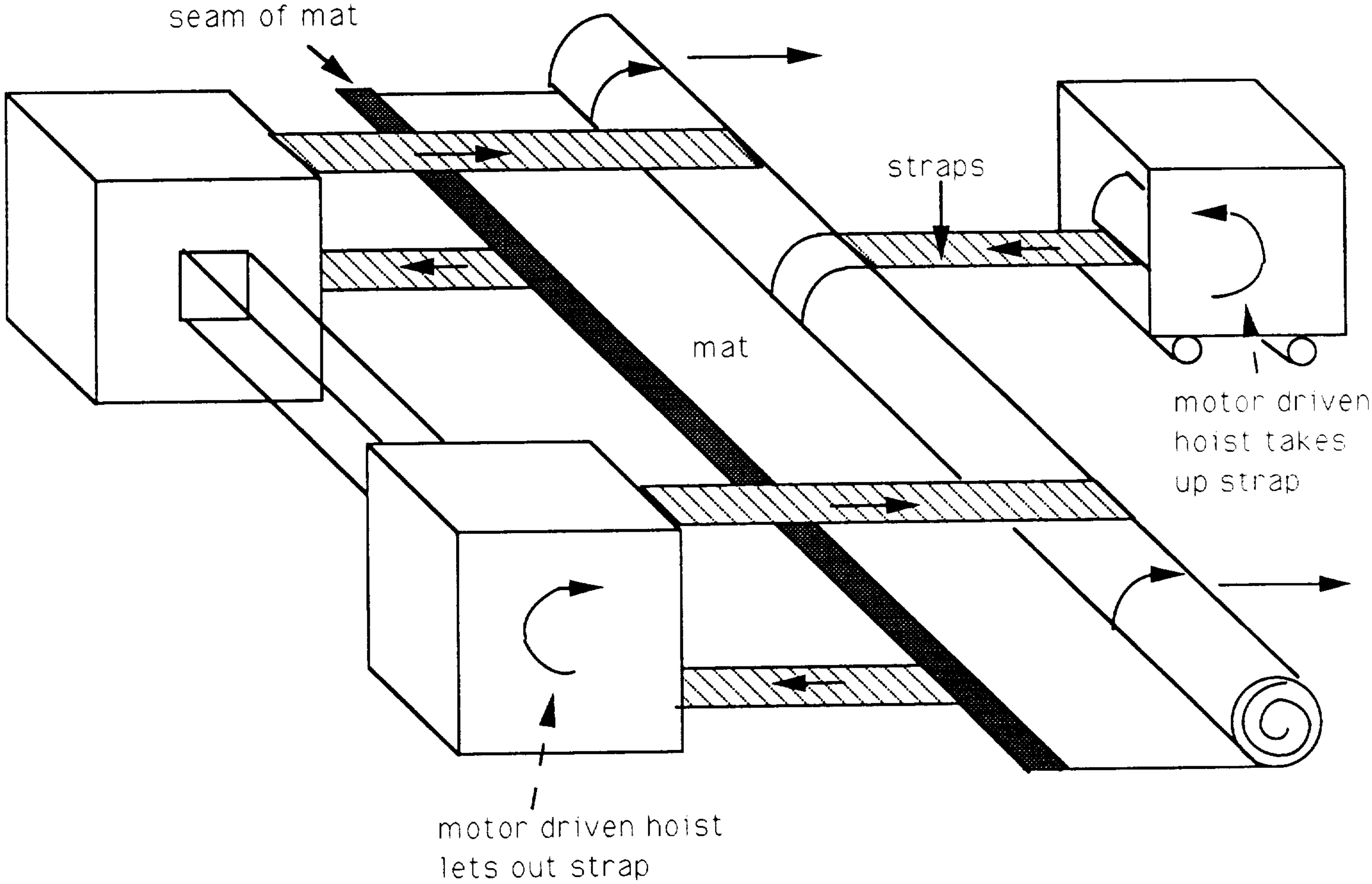
Appendix E

Alternative Deployment Methods

ALTERNATE DEPLOYMENT METHODS



rejected because too complicated and the hoists are
too heavy for the robots to position

Figure E.1

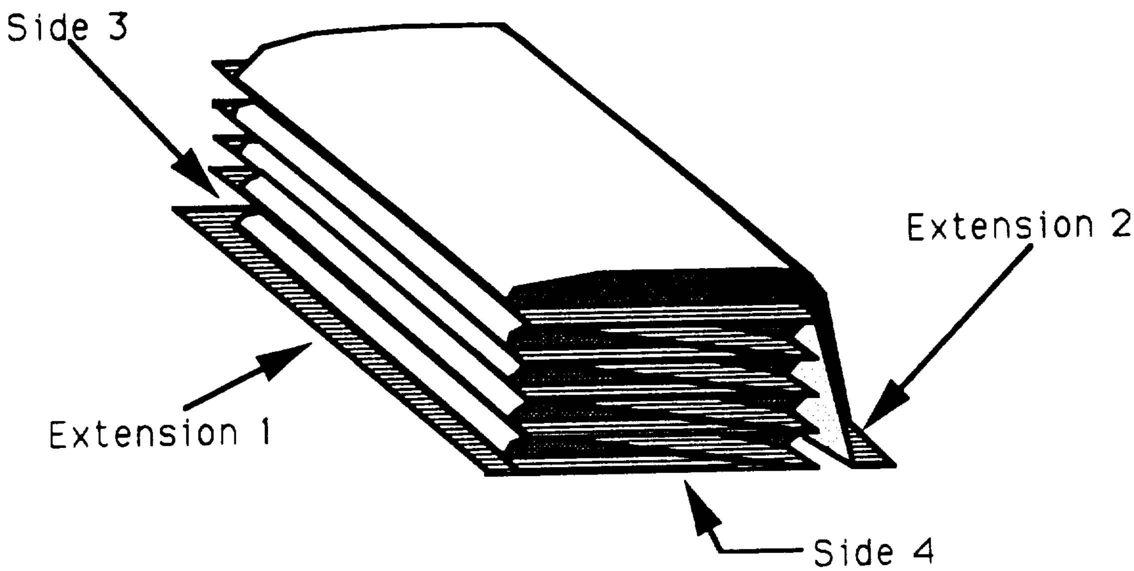


Figure E.2a: Initial Form of the Robotic Deployment Method

Plan for deployment:

1. Robot 1, R1, anchors Extension 1.
2. R1 & R2 clasp Extension 2 and pull it until fully extended.
3. R1 anchors Extension 2 and Side 3.
4. R1, R2 & R3 pull Side 4 until fully extended.
5. R1 then removes all anchors.
6. Process completed.

NOTE:

1. Since time is of lesser importance, only R1 will be capable of anchoring the pad.
2. To allow for more robots, add clasping points on Side 4.

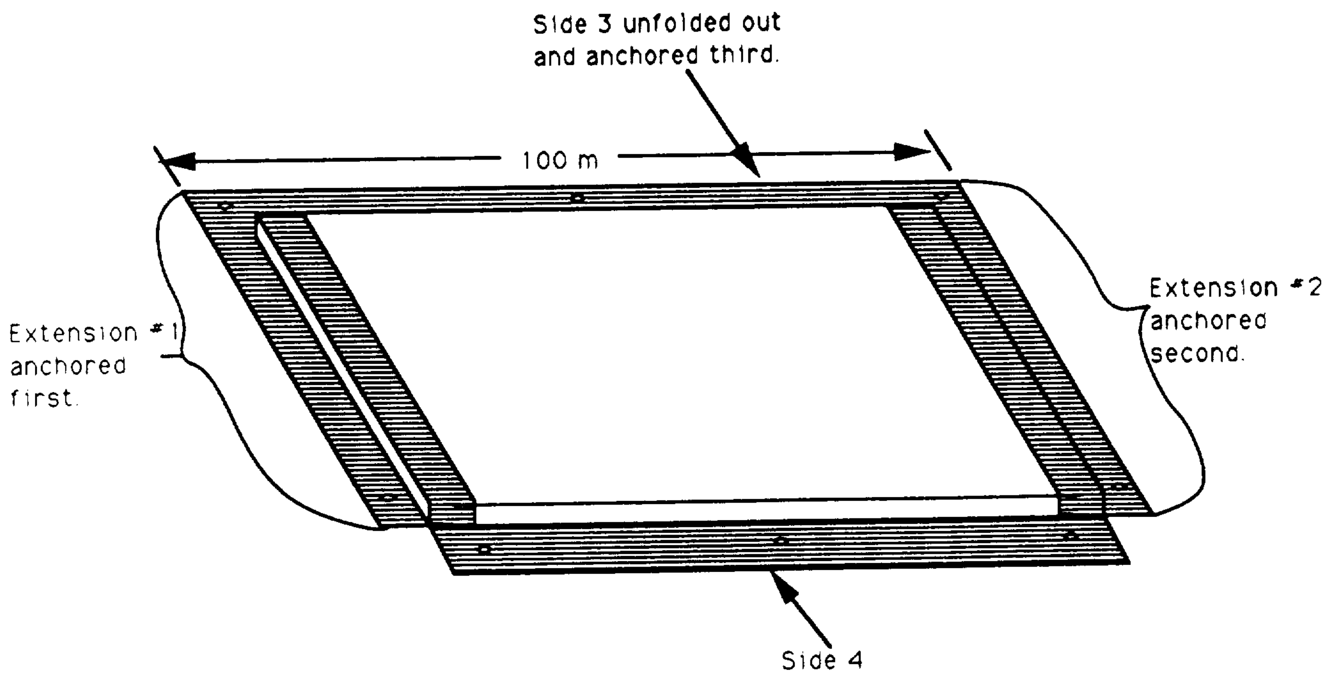


Figure E.2b: Second Form of the Robotic Deployment Method.

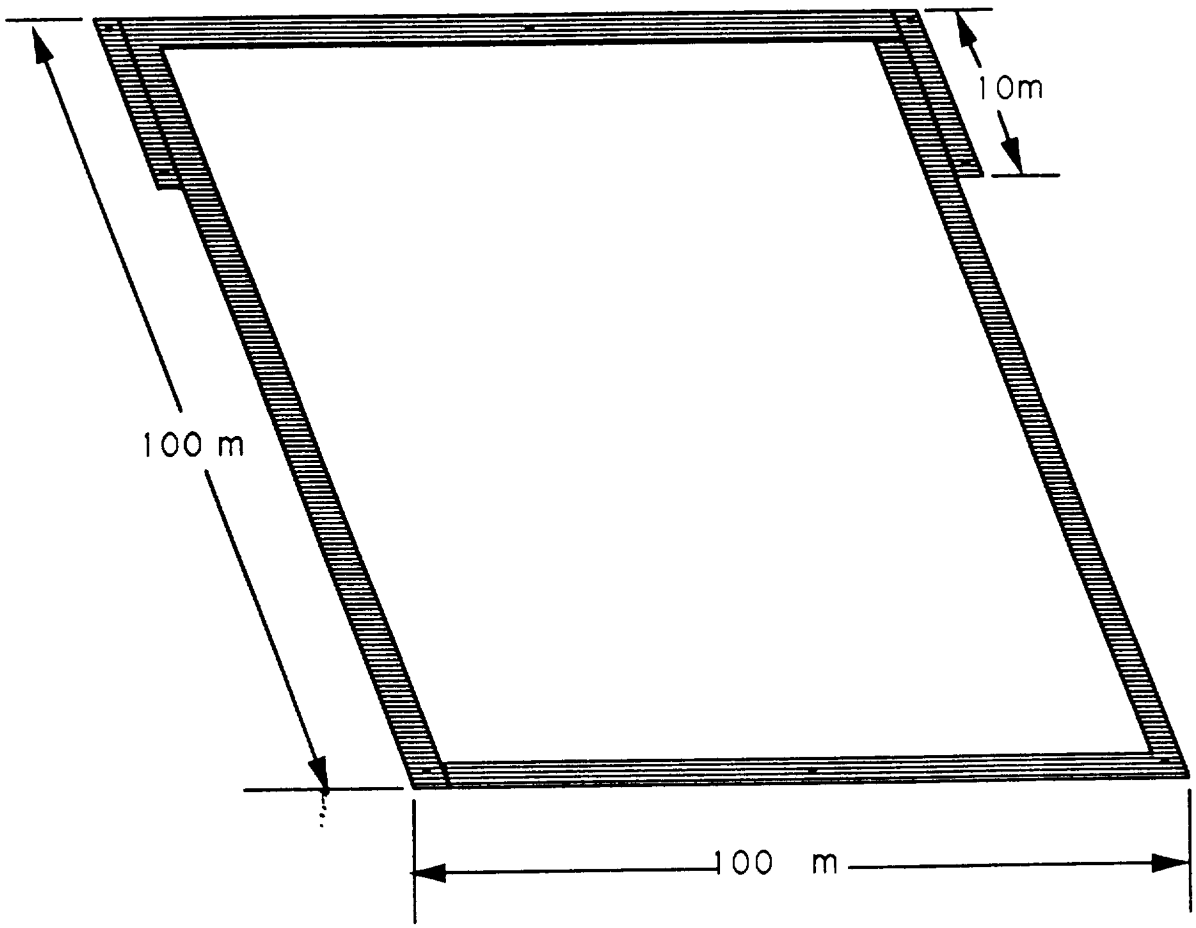
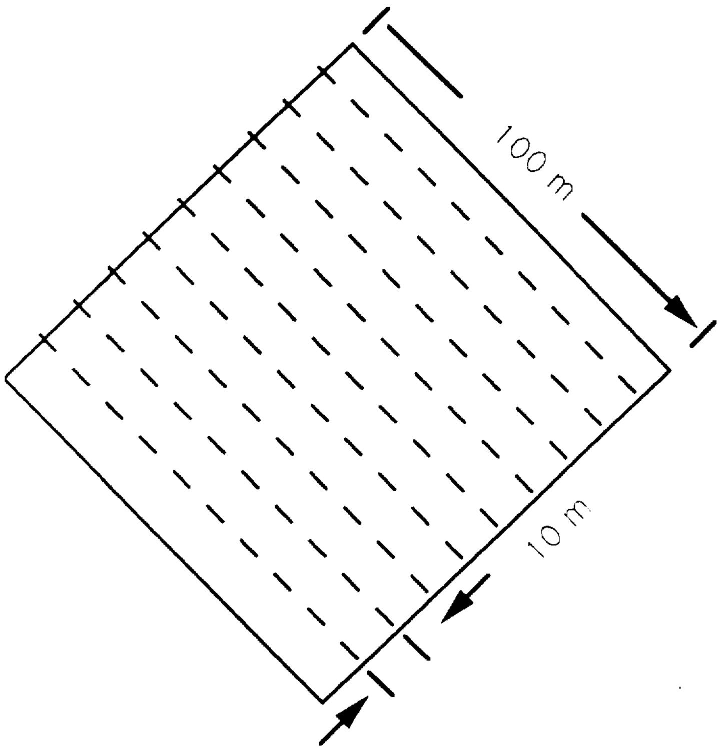


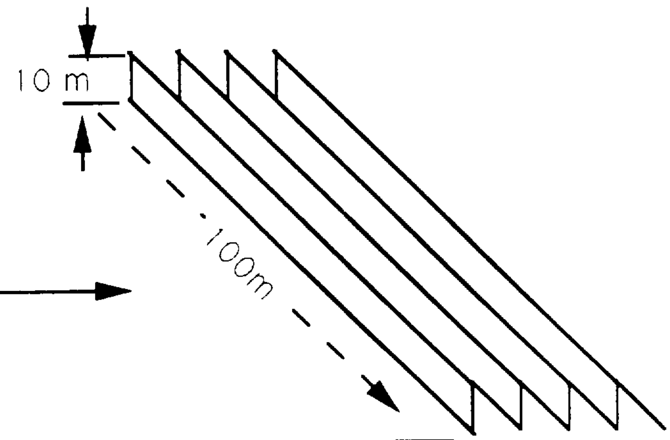
Figure E.2c: Final Form of the Robotic Deployment Method

Appendix F

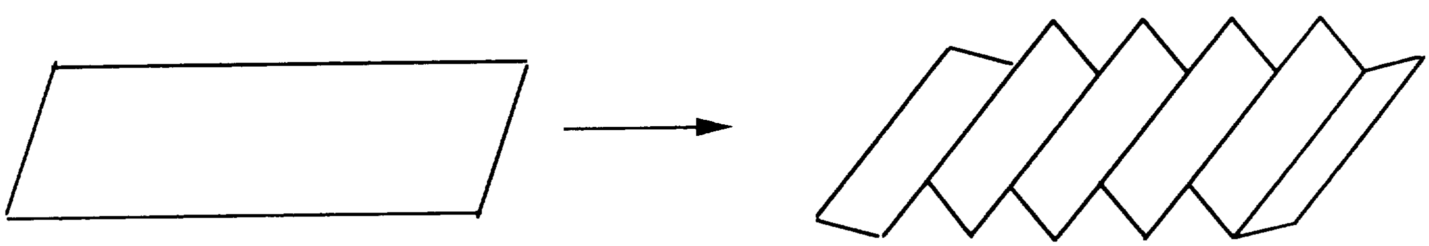
Alternative Stowage Methods

ALTERNATIVE FOLDING METHODS





fold in accordian fashion



fold in accordian fashion
in the other direction

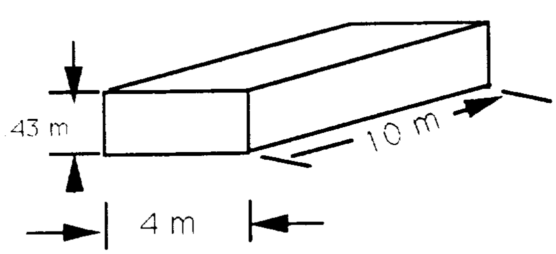


Figure F.2

ALTERNATIVE FOLDING METHODS

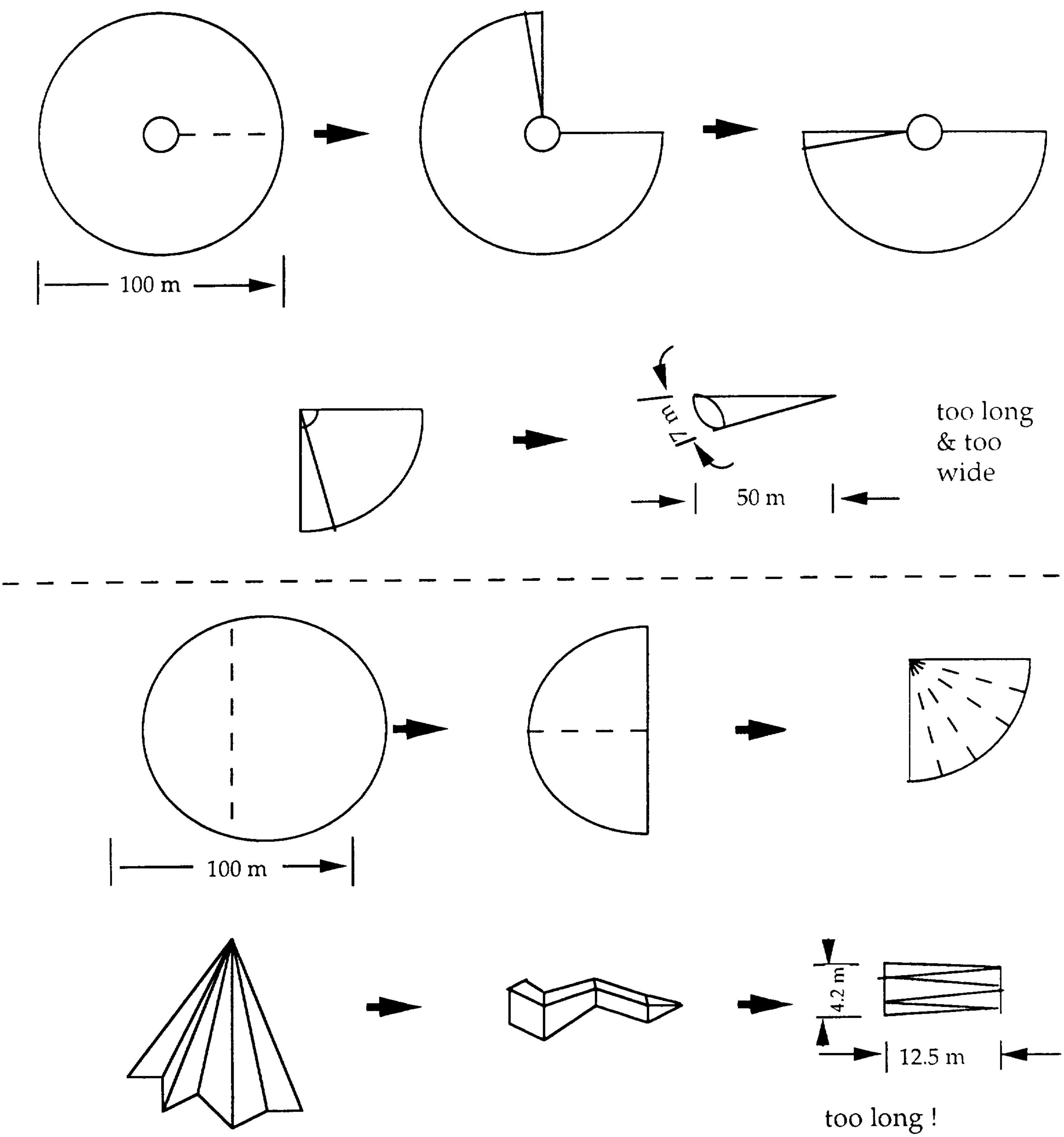


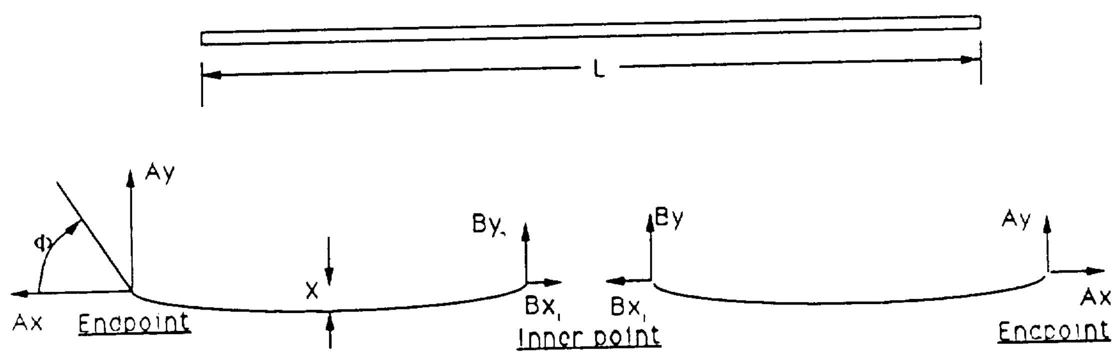
Figure F.1

Appendix G

Stress Analysis of the Mat

Stress Analysis of the Mat

In considering the feasibility of having robots deploy the lunar launch pad, we must consider the weight of the launch pad and the ability of the robots to handle the weight. The required holding force within the robots' arms was studied as a function of the angle that pad makes with the horizon at the holding point.



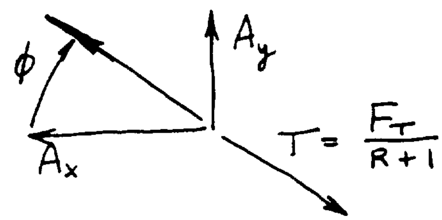
Deflection of launch pad

In the figure, Ax and Ay are the required forces at an endpoint in the horizontal and vertical directions, respectively. Also, Bx and By are the required forces at an inner point in the horizontal and vertical directions, respectively. The required forces were calculated as a function of the angle of incidence, Phi, and are listed in Tables G.1a thru G.1e, where the number of robots varied from two to six, respectively. The length, L, of the material is 100 meters. The deflection, X, of the mat is calculated in Table G.2 as a function of the angle of incidence, Phi, and this relationship is shown in Figure G.2. Sample calculations are shown with Table G.1a. Table G.1b and Table G.2.

Table G.1a

	Phi (deg)	Ax (kN)	Ay (kN)	Bx (kN)	By (kN)
1	45	1.58	1.58	0.0	0.0
2	35	1.83	1.28	0.0	0.0
3	25	2.02	0.94	0.0	0.0
4	15	2.15	0.58	0.0	0.0
5	5	2.22	0.19	0.0	0.0

Force Analysis at an Endpoint - Point A



$$A_x = \left(\frac{F_T}{R+1}\right)\cos\phi$$

$$A_y = \left(\frac{F_T}{R+1}\right)\sin\phi$$

where R = number of robots

ϕ = angle of incidence between mat and horizon

F_T = Weight of 30m x 100m of fabric on moon

$$F_T = \left(\frac{2.23\ N}{1\ m^2\ \text{fabric}}\right)(3{,}000.\ m^2\ \text{fabric})$$

$$\boxed{F_T = 6.68\ kN}$$

With 2 robots,

$$A_x = \frac{6.68\ kN}{(2+1)}\cos\phi = 2.23\ kN\ (\cos\phi)$$

$$A_y = \frac{6.68\ kN}{(2+1)}\sin\phi = 2.23\ kN\ (\sin\phi)$$

Figure G.1a: Required forces to hold mat vs. angle of incidence, using 2 robots.

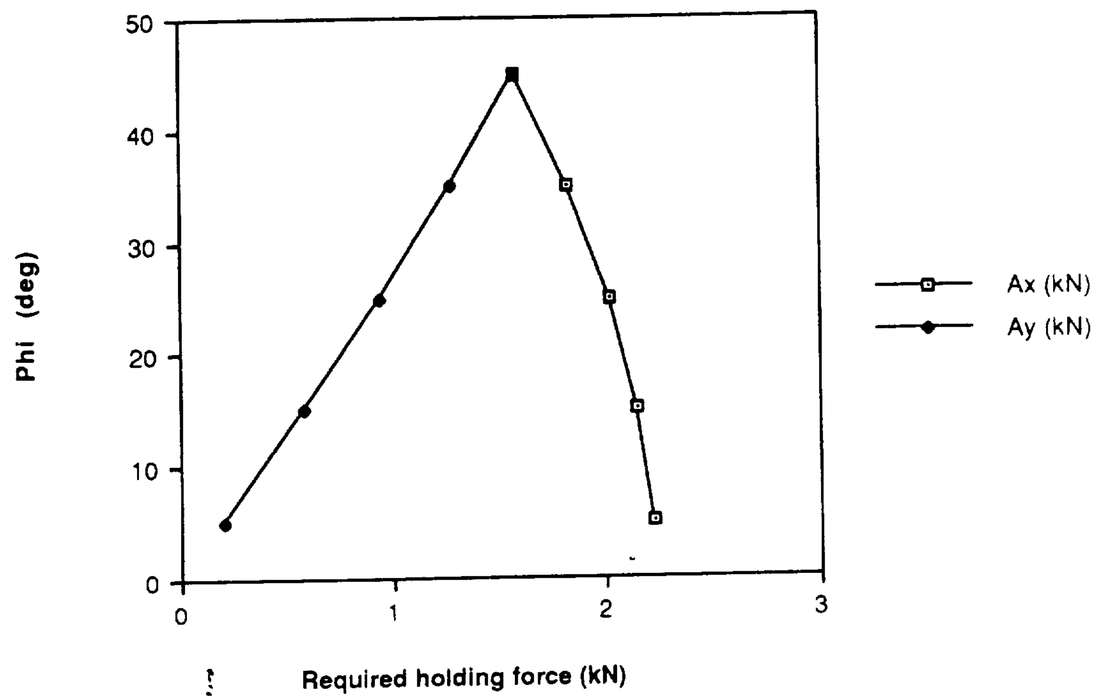
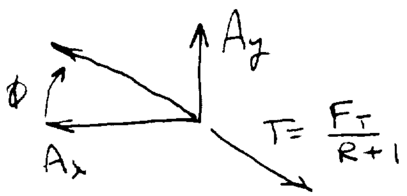


Table G.1b   Mon, Mar 12, 1990 16:33

	Phi (deg)	Ax (kN)	Ay (kN)	Bx (kN)	By (kN)
1	45	1.18	1.180	0.0	2.360
2	35	1.37	0.958	0.0	1.920
3	25	1.51	0.706	0.0	1.410
4	15	1.61	0.432	0.0	0.864
5	5	1.66	0.146	0.0	0.292

Force Analysis at an Endpoint - Point A



$$A_x = \left(\frac{F_T}{R+1}\right)\cos\phi$$

$$A_y = \left(\frac{F_T}{R+1}\right)\sin\phi$$

$F_T = 6.68$ kN

$R = 3$

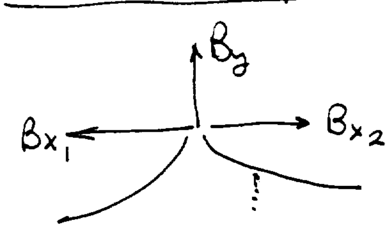
Sample Calculation

if $\phi = 45°$,

$$A_x = \left(\frac{6.68\text{ kN}}{3+1}\right)\cos\phi = 1.18\text{ kN}$$

$$A_y = \left(\frac{6.68\text{ kN}}{3+1}\right)\sin\phi = 1.18\text{ kN}$$

Force Analysis at an Inner Point - Point B



$$B_{x_1} = B_{x_2} = 0$$

$$B_y = 2A_y$$

$$B_y = \left(\frac{2F_T}{R+1}\right)\sin\phi$$

$F_T = 6.68$ kN

$R = 3$

if $\phi = 45°$

$$B_y = \left(\frac{2(6.68\text{ kN})}{3+1}\right)\cos\phi = 2.36\text{ kN}$$

Figure G.1b: Required forces to hold mat vs. angle of incidence, using 3 robots.

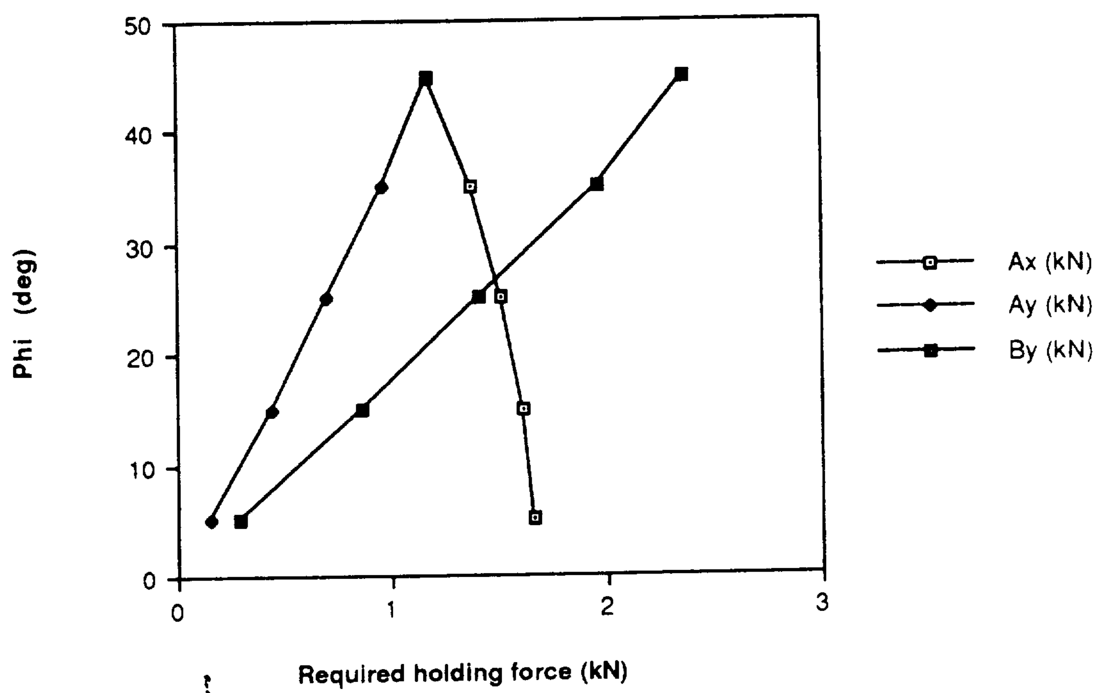


Table G.1c

Phi (deg)	Ax (kN)	Ay (kN)	Bx (kN)	By (kN)
45	0.95	0.948	0.0	1.900
35	1.10	0.769	0.0	1.540
25	1.21	0.566	0.0	1.130
15	1.29	0.347	0.0	0.694
5	1.33	0.117	0.0	0.234

Figure G.1c: Required forces to hold mat vs. angle of incidence, using 4 robots.

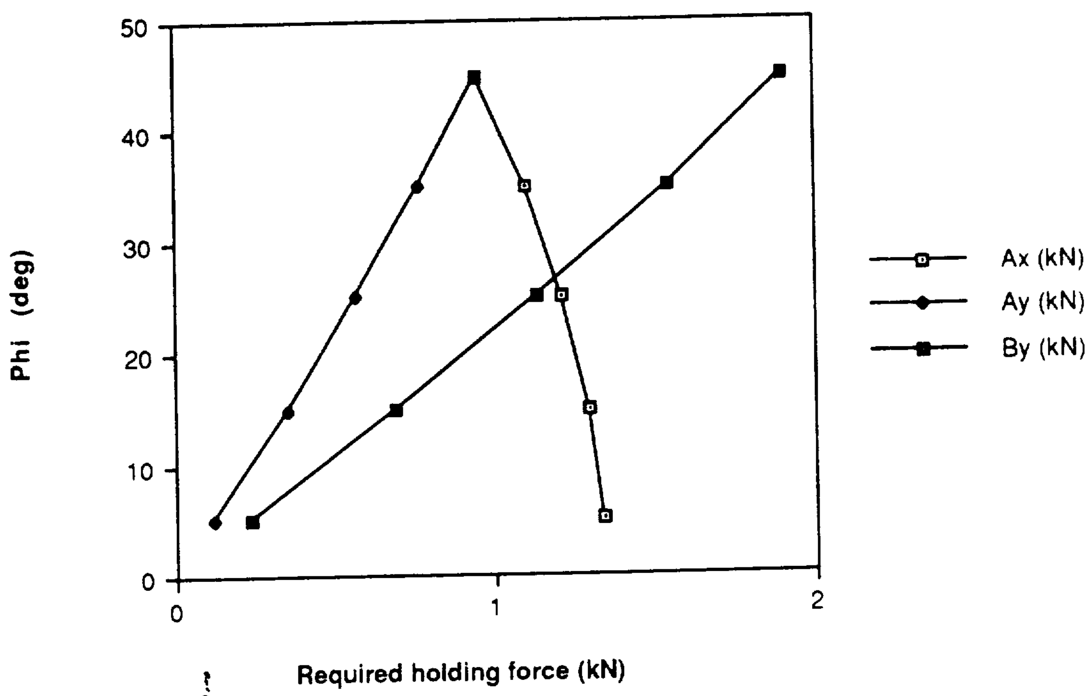


Table G.1d

	Phi (deg)	Ax (kN)	Ay (kN)	Bx (kN)	By (kN)
1	45	0.785	0.785	0.0	1.570
2	35	0.909	0.637	0.0	1.270
3	25	1.010	0.469	0.0	0.938
4	15	1.070	0.287	0.0	0.574
5	5	1.110	0.097	0.0	0.193

Figure G.1d: Required forces to hold mat vs. angle of incidence, using 5 robots.

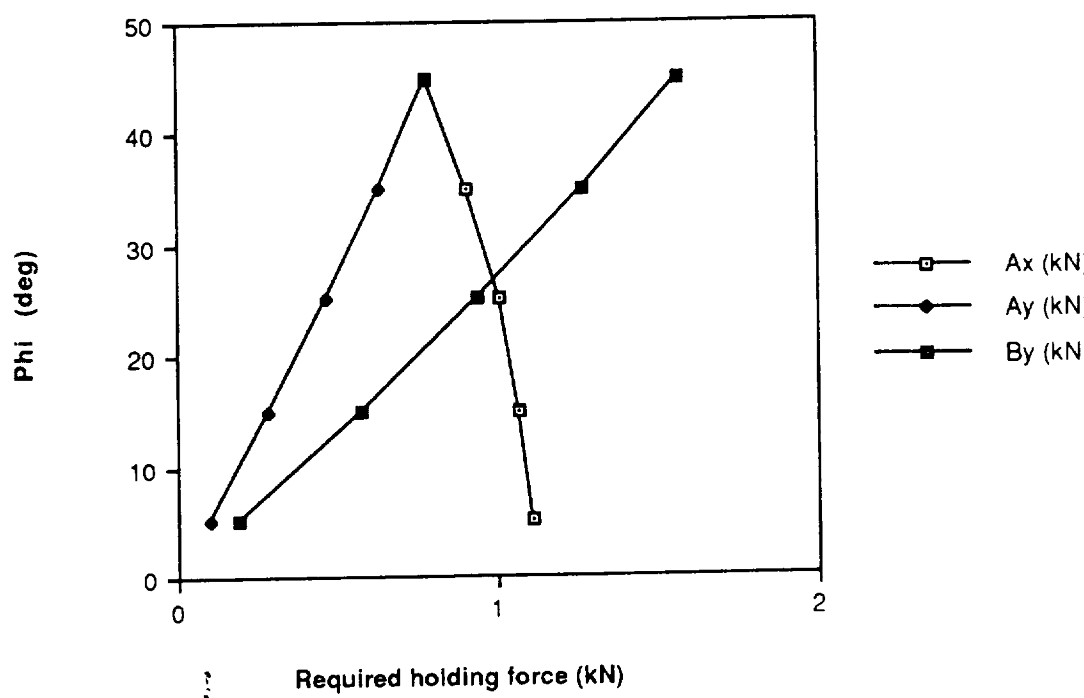


Table G.1e

	Phi (deg)	Ax (kN)	Ay (kN)	Bx (kN)	By (kN)
1	45	0.675	0.675	0.0	1.350
2	35	0.781	0.547	0.0	1.090
3	25	0.865	0.403	0.0	0.806
4	15	0.921	0.247	0.0	0.494
5	5	0.950	0.083	0.0	0.166

Figure G.1e: Required forces to hold mat vs. angle of incidence, using 6 robots.

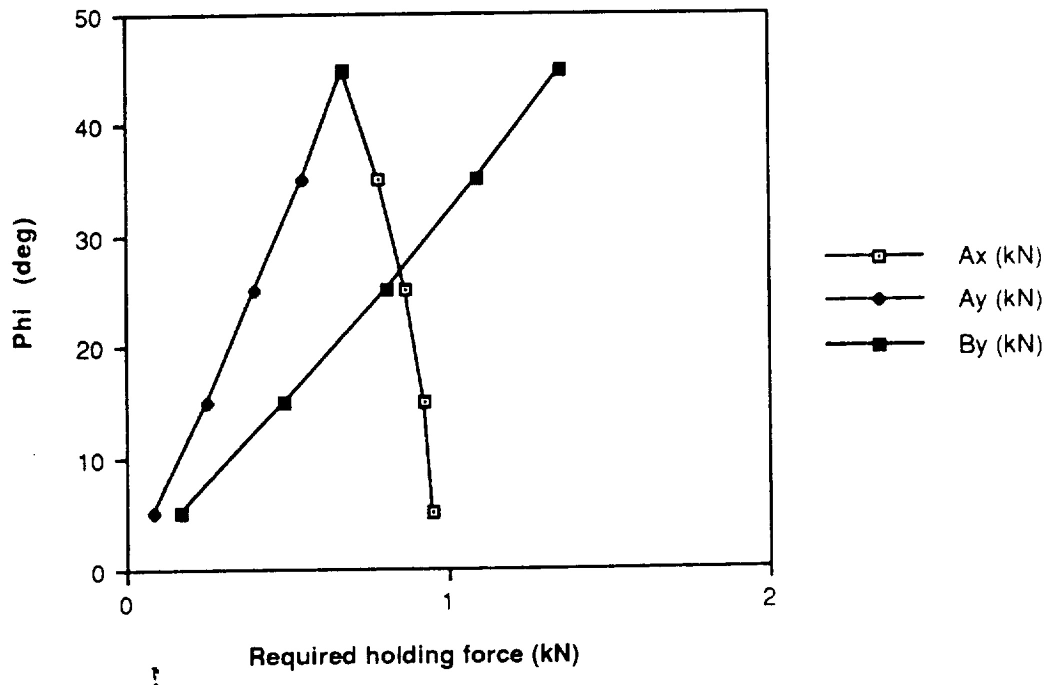
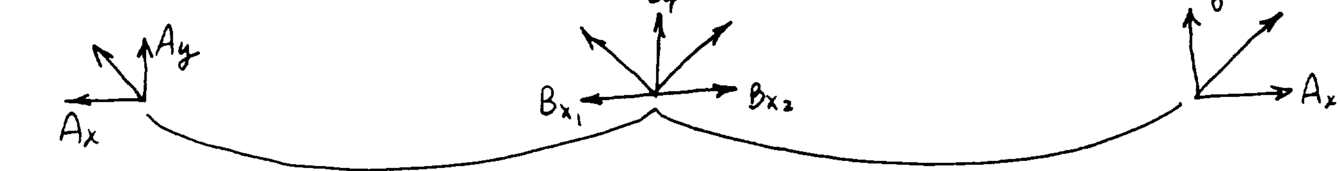
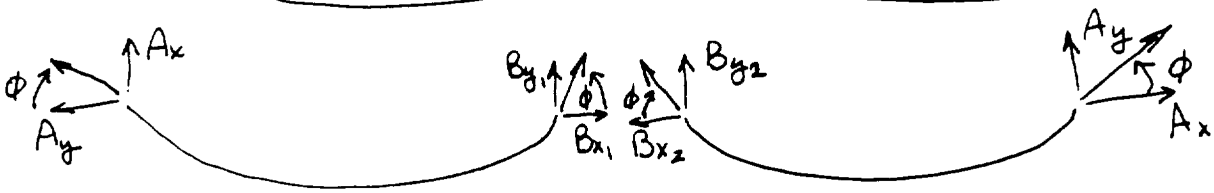


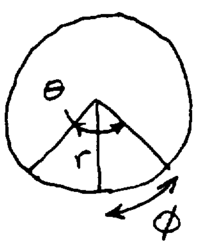
Table G.2

X (meters)

	Phi (deg)	2 robots	3 robots	4 robots	5 robots	6 robots
1	45	18.700	9.350	6.220	4.670	3.740
2	35	14.800	7.420	4.940	3.710	2.970
3	25	10.700	5.380	3.580	2.690	2.150
4	15	6.530	3.270	2.180	1.630	1.310
5	5	2.180	1.090	0.727	0.546	0.437







$\theta = 2\phi$

$\phi = \frac{\theta}{2}$

$P = 2\pi r$

$360° = 2\pi$

$r(1-\cos\phi) = x$

$r = \left(\frac{L}{\theta}\right)\left(\frac{360°}{2\pi}\right) = \frac{57.3 \ L(m)}{\theta(\deg)}$

Solving for x,

$x = [1-\cos\phi]\left(\frac{57.3 L}{\theta}\right)$

$x = \frac{57.3 L}{2\phi}(1-\cos\phi)$

$$\boxed{x = \frac{28.7 L}{\phi}(1-\cos\phi)}$$

In this equation,

L = length of each section held by robots

$$\boxed{L = \frac{100.\text{ meters}}{(R-1)}}$$

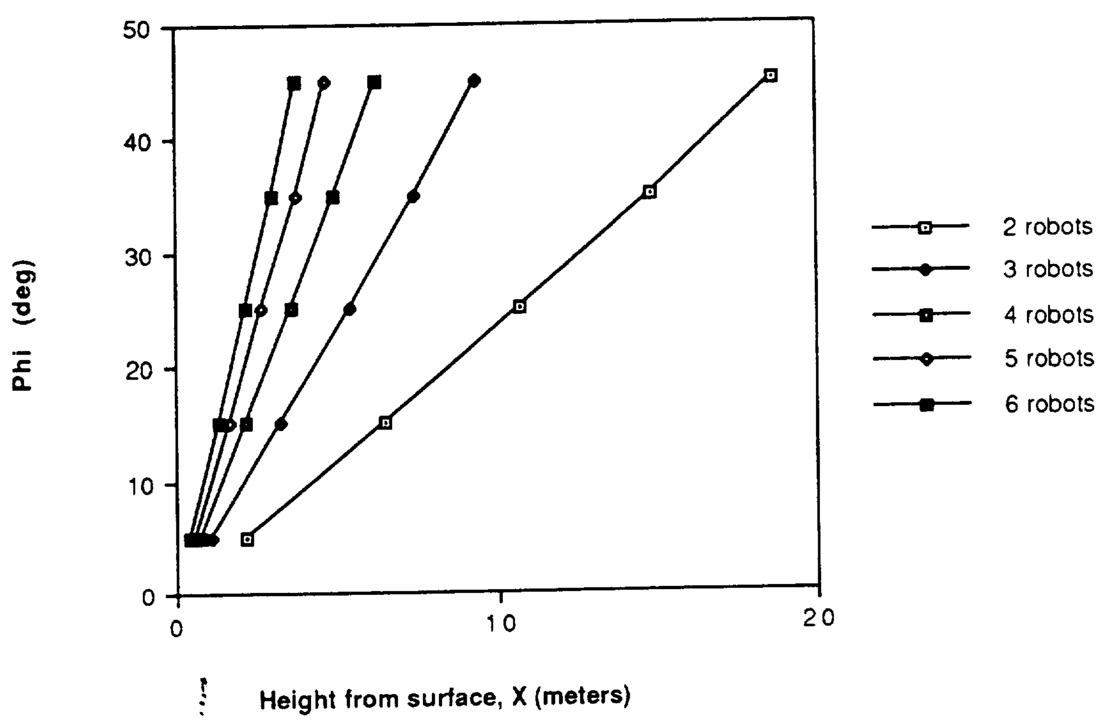
where R = number of robots

<u>Sample Calculation</u>

if $\phi = 45°$ & L = 50 meters

$x = \frac{(28.7)(50)}{45}(1-\cos 45°) = 9.35 m$

Figure G.2: Height from surface vs. angle of incidence



Appendix H

Rocket Engine Plume Analysis

PLUME ANALYSIS

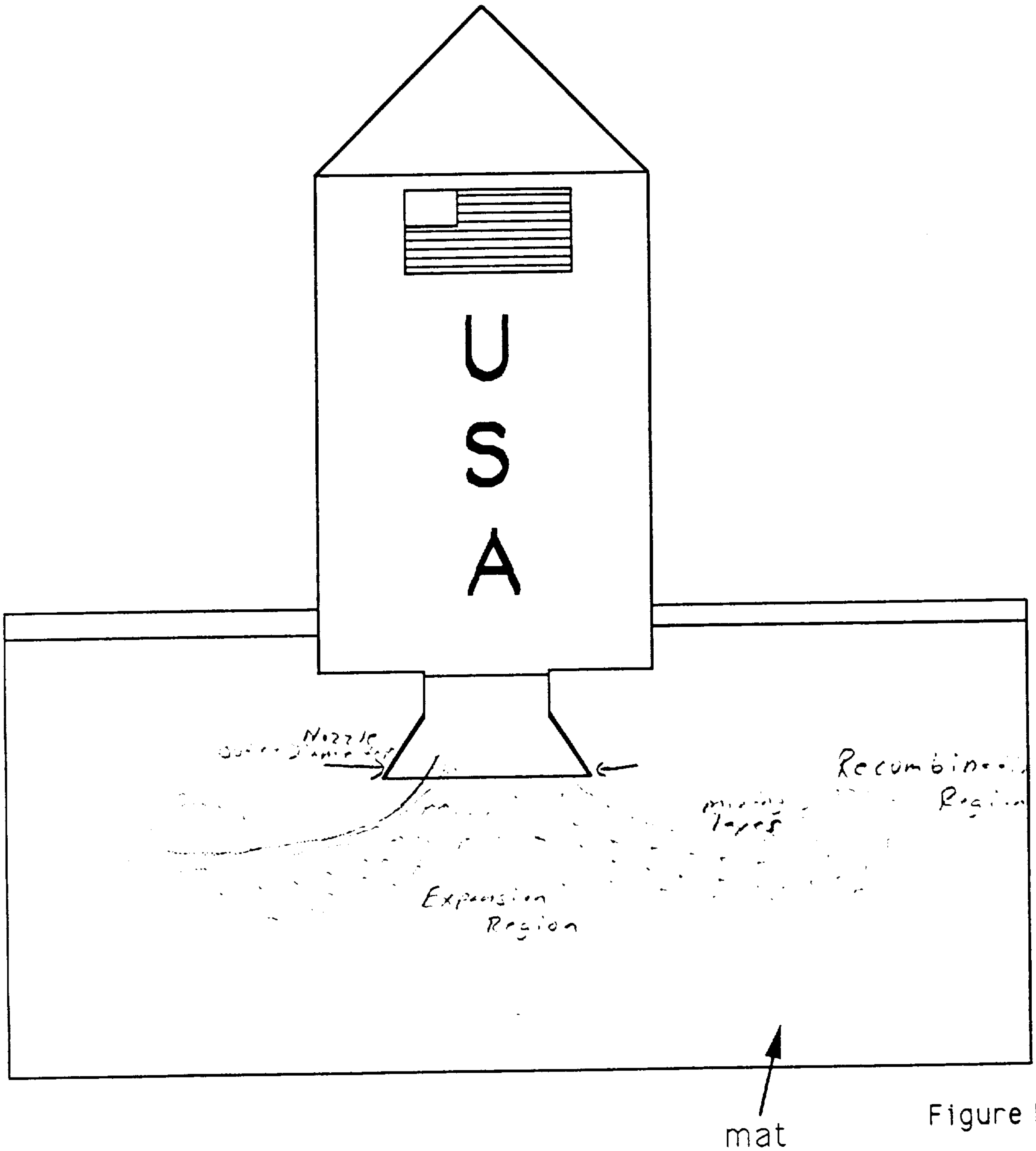


Figure H.1

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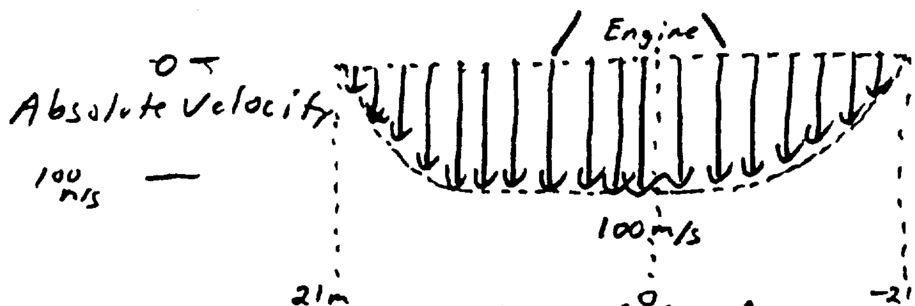
The plume analysis conducted was based on a single engine launch vehicle. The fuel utilized was assumed to be of a liquid nature.

Plume Characteristics:

Temp. of Gases $\approx 1500\,^{\circ}C$

Velocity Profile



With a design lift off force of $3.26\ m/s^2$ × Spaceship mass (≈ 21unarg's) and based on the given engine nozzle exit diameter (3-6m). The exit velocity of the gases will be ≈ $100\ m/s^2$ At takeoff, The plume is in an overexpanded condition. Jannaf suggests. that the velocity profile will extend 3 - 3½ diameters from the center. ~~At height~~

$3.5 \times 6 = 21\ m$ from center

At this point, due to recombination of the plume, the absolute velocity falls to ≈ 0.

Pressure (Force) Profile

The pressure on the moon (in a vacuum) would be

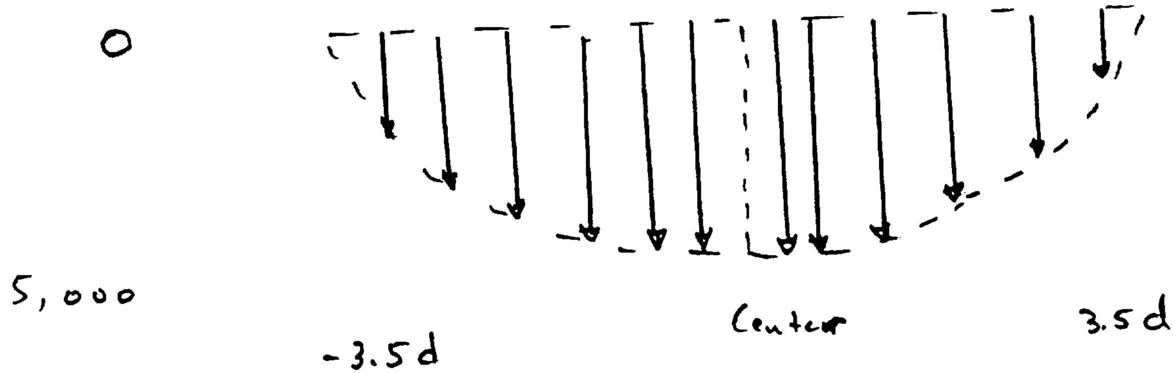
$$P_0 = \cancel{P_{atm}}^{0} + \frac{1}{2}\rho V^2$$

$$P_0 = \frac{1}{2}\rho V_{exit}^2$$

Using a maximum density for the exhaust gases of $1\ kg/m^3$ (water, gases less than liquid)

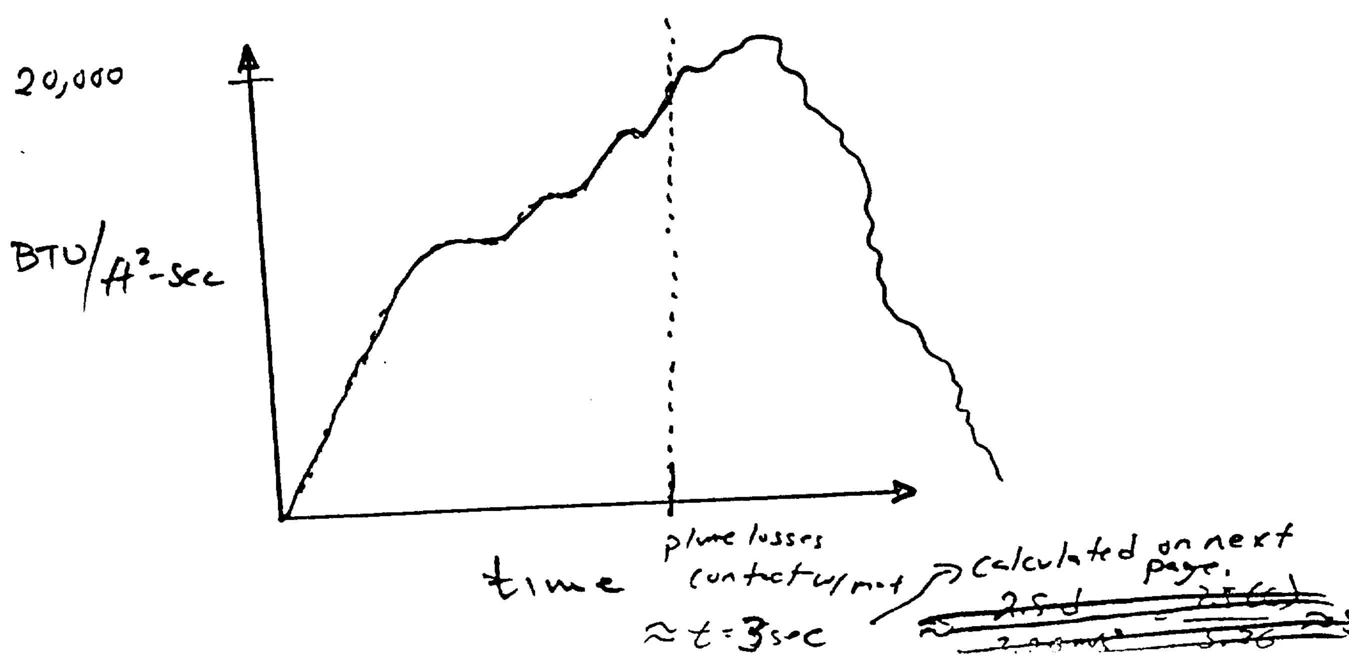
$$P_0 = \frac{1}{2}(1.00)^2(1) = 5{,}000\ N/m^2$$

PRESSURE PROFILE



HEAT TRANSFER

THE HEAT transfered to the mat will be as a result of both radiation and conduction. Radiation effects are very dominant. In addition, the heat rate varies with time rather than distance. See figure below.



Jannat also suggests that the maximum distance the plume will extend down stream is $\approx 2.5\,d$. 7

$$2.5\,d = 2.5 \times 6 = 15\,m$$

the time at which the plume will lose contact with the mat is found by

$$y = y_0 + V_0 t + \frac{1}{2} a t^2$$

$$15 = 0 + 0 + \frac{1}{2}(3.26)\,t^2$$

$$\frac{30}{3.26} = t^2$$

$$t = 3.03\ \text{sec}$$

used in graph on preceding page

Appendix I

Projectile Force Calculations

PROJECTILE FORCE CALCULATION

Using the WORK ENERGY PRINCIPLE

$\Delta T = W_{i \to f}$ where ΔT is the change in kinetic energy.

Thus,

$$\Delta T = W_{i \to f}$$

$$T_f - T_i = W_f - W_i$$

$$+\frac{1}{2} m \cancelto{0}{v_f^2} - \frac{1}{2} m v_i^2 = \cancelto{0}{W_f} - W_i$$

$\Rightarrow \quad W_i = \frac{1}{2} m v_i^2$ where

$W_i = \int_0^{100} F \, dr.$ where $F = \frac{\omega}{100} x.$

ω is the weight of the mat.

Hence,

$$\frac{1}{2} \frac{\omega}{g} v_i^2 = \int_0^{100} \frac{\omega}{100} x \, dx.$$

Therefore, $$\frac{1}{2}\frac{W}{g}v_i^2 = \frac{W}{200}x^2\Big|_0^{100}$$

$$\frac{W}{g}v_i^2 = 100W$$

$$v_i^2 = 100g$$

For earth conditions. $g = 9.81\ m/s^2$

$$\Rightarrow v_i^2 = 981\ m^2/s^2$$

$$\underline{\underline{v_i = 31.321\ m/s}}$$

FROM the momentum force equation

$$F = mV_f - mV_i$$

$$= \frac{W}{g}(\cancelto{0}{V_f} - V_i)$$

$$= \frac{W}{g}(-31.321) = -3.193W$$

the negative sign here denote the mat force.

$$F^* = F\sin\theta = 3.193W\sin\theta$$

where F^* is the needed force to spread out the mat.

For moon conditions. $g_m \doteq \frac{1}{6} g_e \doteq 1.635\, m/s^2$

$$\Rightarrow \quad v_i^2 = 163.5\, m^2/s^2$$

$$\underline{\underline{v_i = 12.787\, m/s}}$$

From the momentum force equation

$$F = m(\cancel{V_f} - V_i) \quad V_f \to 0$$

$$= \frac{W}{g}(-12.787) = -1.303W$$

F, Here is the force applied by the mat.

thus,

$$F^* = F\sin\theta = 1.303\, W\sin\theta$$

where F^* is the actual force needed to spread out the mat.

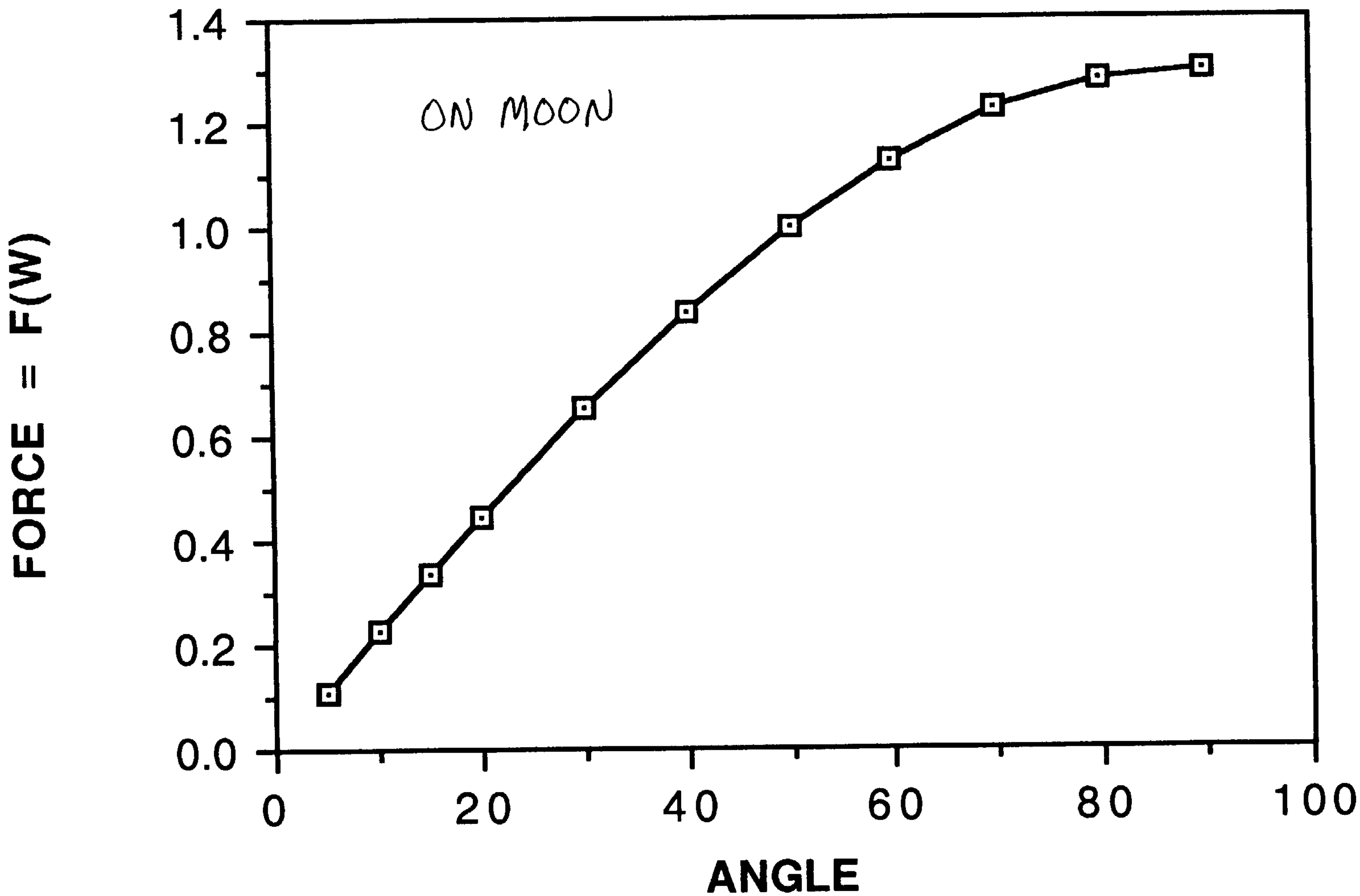
Appendix J

Vehicle Parameter Analysis

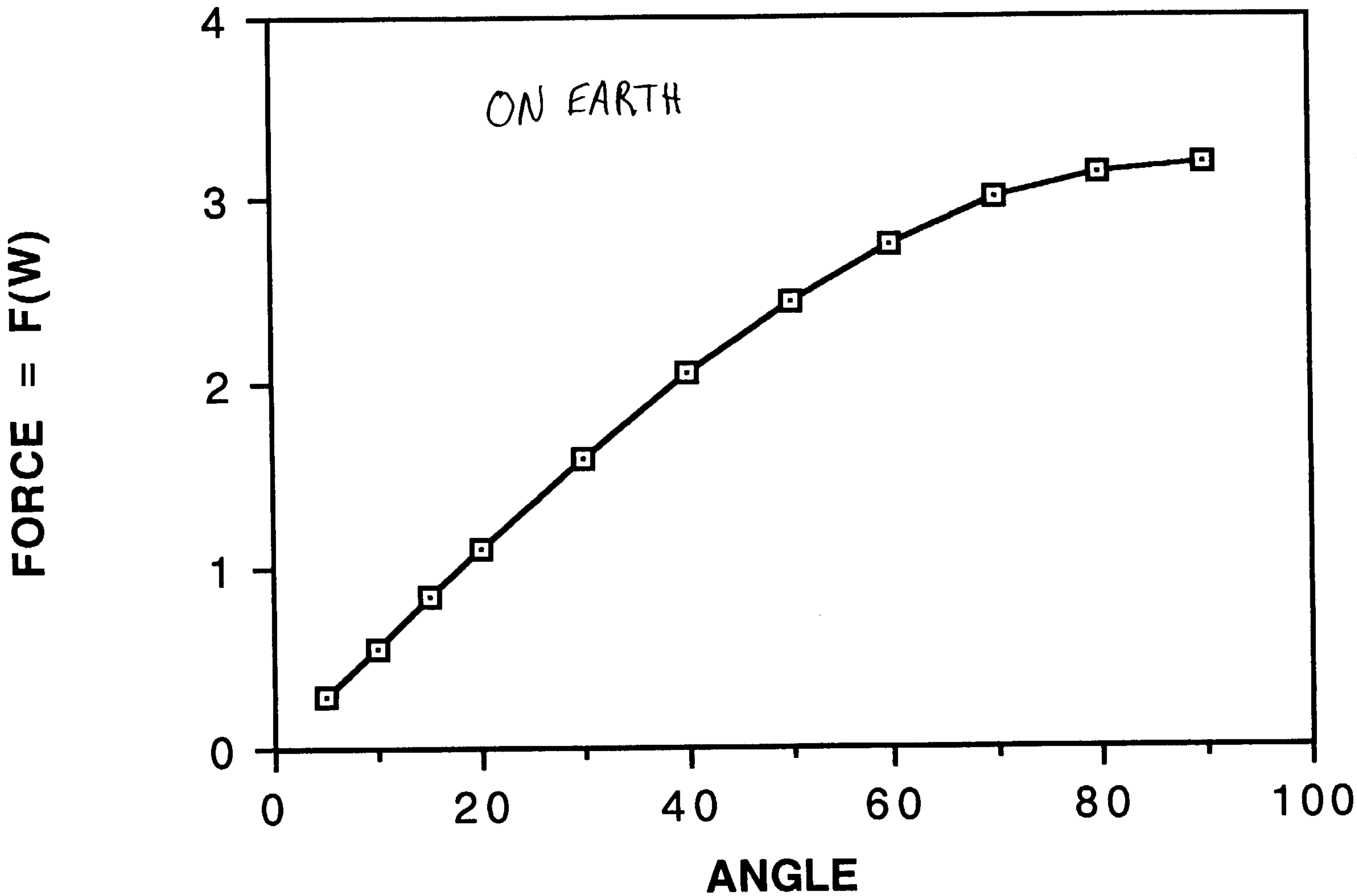
Vehicle Parameters

The Agena is the satellite rocket vehicle used in the Discoverer, MIDAS, and SAMOS programs. The basic vehicle, which is manufactured by Lockheed Aircraft Corp., is 5.7912 meters (19 feet) long and 1.5240 meters (5 feet) in diameter and weighs 8,500 pounds at launch; the modified vehicle is 6.7056 meters (22 feet) long and weighs 12,00 pounds at launch. The X-15 Manned Vehicle is 15.240 meters (50 feet) and weighs more than 31,000 pounds. The maximum cargo weight (i.e. maximum weight of the mat) is 60,000 pounds. Thus, the rocket plus cargo weight will yield total weight between 80,000 to 95,000 pounds. The fuel rate was taken from the calculated theoretical performance of the Neptune Rocket which is 45.1lbs/sec of alcohol and 50.1 lbs/sec for oxygen.

Data from "FORCE AS A FUNCTION OF ANGLE"



Data from "FORCE AS A FUNCTION OF ANGLE"



Appendix K

Fabric Characteristics

FIBERS/FABRICS

The choice of fiber will influence the basic tensile and compressive strength and stiffness, electrical and thermal conductivity, and thermal expansion. The cost of the composite is also strongly influenced by the fiber selected.

Fiberite offers a complete range of fibers from all manufacturers of these materials, as well as hundreds of woven fabric styles and weights.

The charts shown here will help you define a fabric or fiber to suit your needs. Used with the preceding chart on resins, you can then pick the optimum composite material for nearly any design requirement.

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Fibers

Code	Type/Base	Manufacturer	Typical Values				Comments and Tow Sizes
			Modulus (MSI)	Strength (KSI)	Density (GM/CC)	Strain (%)	
T-300	Pan-Carbon	Union Carbide/Toray	33	480	1.75	1.4	1K, 3K, 6K, 12K
T-500	Pan-Carbon	Union Carbide/Toray	34	520	1.78	1.55	3K, 6K, 12K
T-700	Pan-Carbon	Toray	36	650	1.80	1.8	3K, 6K
T-40	Pan-Carbon	Toray	43	610	1.74	1.4	6K
Pan 50	Pan-Carbon	Toray	57	350	1.81	0.6	3K and 6K
M46	Pan-Carbon	Toray	65	310	1.90	0.5	6K
Pitch 55	Pitch-Carbon	Union Carbide	55	250	2.00	0.5	2K and 4K
Pitch 75	Pitch-Carbon	Union Carbide	75	300	2.00	0.4	1K and 2K
Pitch 100	Pitch-Carbon	Union Carbide	105	325	2.15	0.3	2K
AS-4	Pan-Carbon	Hercules	33.5	528	1.78	1.52	3K, 6K, 12K
AS-6	Pan-Carbon	Hercules	35.5	617	1.87	1.66	12K
IM-6	Pan-Carbon	Hercules	44.6	703	1.80	1.66	12K
HMS-4	Pan-Carbon	Hercules	52.0	550	1.84	1.10	12K
Celion	Pan-Carbon	Celanese Toho	34	515	1.77	1.5	1K, 3K, 6K, 12K
Celion ST	Pan-Carbon	Celanese Toho	34	630	1.78	1.8	3K, 6K, 12K
G-50	Pan-Carbon	Celanese Toho	52	360	1.78	0.7	6K, 12K
GY-70	Pan-Carbon	Celanese	70	220	1.96	0.3	Single-End and 3" Wide Band
XAS	Pan-Carbon	Grafil-Hysol	34	500	1.84	1.45	6K, 12K
EXAS	Pan-Carbon	Grafil-Hysol	34	560	1.85	1.65	3K, 6K, 12K
HM-S	Pan-Carbon	Grafil-Hysol	49.5	365	1.91	0.74	6K, 10K, 12K
Hi-Carbalon	Pan-Carbon	Asahi-Nippon Carbon	35	620	1.87	1.77	3K, 6K, 12K
RK-30	Pan-Carbon	RK Textiles	33	420	1.78	1.3	12K
Kevlar 49	Aramid	Dupont	19	525	1.45	2.8	195 to 7100 Denier
E-Glass	Glass	Owens-Corning PPG	10.5	500	2.54	4.8	12 and 30-End Roving
S-2 Glass	Glass	Owens-Corning	12.6	625	2.49	5.0	20-End Roving
Nicalon	SiC	Nippon Carbon	27	390	2.6	1.4	2300°F Resistant
Nextel	Alumina-Boria-Silica	3M	22	250	2.7	1.1	3000°F Resistant

Fabrics

Style	Oz/sq yd – GM/M² Nominal	Fabric Thickness (Mils)	Estimated Cured Ply (Mils)	Yarn Count Warp & Fill Construction	Yarn Type Warp & Fill	Fiber	Weave	Ratio Warp/Fill Properties Tensile - Mod	Fiber Properties	
									Tensile x 100C Warp/Fill	Mod x 10⁶ Warp/Fill
W-107	10.00 - 339	16.0	13	24 x 24	T-300 3K/T-300 3K	Graphic/Kevlar	8HS	1:1	470/470	33.5/33.5
W-133	10.80 - 366	17.0	13	24 x 23	T-300 3K/T-300 3K	Graphite	8HS	1:1	470/470	33.5/33.5
W-134	5.63 - 191	12.5	7	12.5 x 12.0	T-300 3K/T-300 3K	Graphite	Plain	1:1	470/470	33.5/33.5
W-166	7.36 - 250	12.0	9	48 x 48	T-300 1K/T-300 1K	Graphite	12HS	1:1	500/500	33.5/33.5
W-196	3.68 - 125	7.5	5	24 x 24	T-300 1K/T-300 1K	Graphite	Plain	1:1	500/500	33.5/33.5
W-320	6.40 - 217	12.0	8	7 x 7	T-300 6K/T-300 6K	Graphite	Plain	1:1	470/470	33.5/33.5
W-322	5.71 - 194	10.0	7	12.5 x 12.5	T-300 3K/T-300 3K	Graphite	Plain	1:1	470/470	33.5/33.5
W-176	3.67 - 124	7.0	5	24 x 24	T-300 1K/T-300 1K	Graphite	5HS	1:1	500/500	33.5/33.5
W-341	3.67 - 125	7.0	5	24 x 24	T-300 1K/T-300 1K	Graphite	Plain	1:1	500/500	33.5/33.5
W-371	8.28 - 281	12.0	10	18 x 18	T-300 3K/T-300 3K	Graphite	5HS	1:1	470/470	33.5/33.5
W-398	11.03 - 373	15.0	13	12 x 12	T-300 6K/T-300 6K	Graphite	5HS	1:1	470/470	33.5/33.5
W-537	5.60 - 189	8.0	6	15 x 15	P-75 S 1K/P-75 S 1K	Pitch	2 x 2 Twill	1:1	500/500	33.5/33.5
W-705	5.86 - 199	8.5	7	12 x 10	T-300 6K/150 I/O Glass	Graphite/S2 Glass	Plain	Unidirectional	470/470	33.5/33.5
W-721	7.36 - 250	13.5	8	8 x 8	T-300 6K-Fiberglass/ T-300 6K-Fiberglass	Graphite/S2 Glass	Plain	1:1	470/470	33.5/33.5
W-1377	20.00 - 678	33.0	25	11 x 11	12K Graphite/ 12K Graphite	Graphite	2 x 2 Basket	1:1	470/470	33.5/33.5
W-2548	11.00 - 373	18.5	13	12 x 12	T-250 6K/T-250 6K	Graphite	CFS	1:1	470/470	33.5/33.5
W-2534	5.63 - 191	12.5	7	12.5 x 12	T-300 3K/T-300 3K	Graphite	Plain	1:1	470/470	33.5/33.5
W-2351 ±45°	5.71 - 193	12.0	.012"	12.5 x 12.5	T-300 3K Toray	Graphite	Plain	1:1	470/470	33.5/33.5

Appendix L

Fabric Samples

Appendix M

Glossary

GLOSSARY

Basket weave - A weave where groups of adjacent warps are each woven as one and picks are inserted in groups of two or more in each shed. the formation resembles a plaited basket

Float - A yarn in a fabric that passes over two or more crosswise yarns.

Pitch - Includes materials composed of polyvinyl chloride (PVC), petroleum asphalt, or coal tar.

Modulus - Describes the degree of elasticity with respect to a force.

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